



Meteorological Services  
Annual Data Report for 2019

John Heiser & Scott Smith  
Meteorological Services  
Environmental & Climate Sciences Department  
Brookhaven National Laboratory

January 2020

**Environmental & Climate Sciences Department**

**Brookhaven National Laboratory**

P.O. Box 5000

Upton, NY 11973-5000

[www.bnl.gov](http://www.bnl.gov)

Notice: This manuscript has been authored by employees of Brookhaven Science Associates, LLC under Contract No.DE-SC0012704 with the U.S. Department of Energy. The publisher by accepting the manuscript for publication acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes.

## **DISCLAIMER**

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

## Table of Contents

Purpose.....	1
Background .....	1
Site .....	2
Instrument Towers .....	2
85-meter Tower.....	2
10-meter Tower.....	3
2-meter pole .....	3
Solar Base Station .....	3
Calibrations .....	4
Data Sets and Data Availability .....	4
Meteorological Data Recovery for 2019.....	5
Air Temperature.....	8
Barometric Pressure .....	27
Relative Humidity .....	34
Rainfall.....	42
Wind Direction and Wind Speed .....	53
2019 Solar Resource Data.....	94
Global Solar Radiation.....	94
Diffuse Solar Radiation.....	99
Direct Solar Radiation.....	99
Long-wave Far Infrared Radiation.....	99
LISF and NSERC Reference Pyranometers .....	99
References.....	143

## List of Tables

Table 1. 2019 Extremes and Totals.....	6
Table 2. Historic Extremes .....	7
Table 3. Monthly Temperature Summary.....	10
Table 4. Historic Monthly Mean Temperatures (°C) for Brookhaven National Laboratory from 1949 to present (@ 2 meters).....	18
Table 5. Historic Monthly Mean Maximum Temperatures (°F) for Brookhaven National Laboratory from 1949 to present (@ 2 meters) .....	21
Table 6. Historic Monthly Mean Minimum Temperatures (°F) for Brookhaven National Laboratory from 1949 to present (@2 meters).....	24
Table 7. Historic Monthly Precipitation for Brookhaven National Laboratory from 1949 to present (@ 2 meters).....	50
Table 8. Average Daily Solar Irradiance (Global) at BNL by Month (W/m <sup>2</sup> ) .....	95

## List of Figures

Figure 1. Average Daily Temperature taken at the 2 meter height at BNL for 2019 .....	9
Figure 2. Daily Minimums and Maximums in Temperature taken at the 2 meter height at BNL for 2019 .....	9
Figure 3. Monthly Mean Temperatures (°C) at Brookhaven National Laboratory for 2019.....	11
Figure 4. Average yearly temperature at Brookhaven National Laboratory – 1949 to present....	11
Figure 5. Air Temperature for the Month of January 2019 .....	12
Figure 6. Air Temperature for the Month of February 2019 .....	12
Figure 7. Air Temperature for the Month of March 2019 .....	13
Figure 8. Air Temperature for the Month of April 2019 .....	13
Figure 9. Air Temperature for the Month of May 2019 .....	14
Figure 10. Air Temperature for the Month of June 2019 .....	14
Figure 11. Air Temperature for the Month of July 2019 .....	15
Figure 12. Air Temperature for the Month of August 2019 .....	15
Figure 13. Air Temperature for the Month of September 2019.....	16
Figure 14. Air Temperature for the Month of October 2019.....	16
Figure 15. Air Temperature for the Month of November 2019.....	17
Figure 16. Air Temperature for the Month of December 2019 .....	17
Figure 17. Average Daily Barometric Pressure at Brookhaven National Laboratory for 2019.....	27
Figure 18. Barometric Pressure for the Month of January 2019.....	28
Figure 19. Barometric Pressure for the Month of February 2019.....	28
Figure 20. Barometric Pressure for the Month of March 2019.....	29
Figure 21. Barometric Pressure for the Month of April 2019.....	29
Figure 22. Barometric Pressure for the Month of May 2019.....	30
Figure 23. Barometric Pressure for the Month of June 2019.....	30
Figure 24. Barometric Pressure for the Month of July 2019 .....	31
Figure 25. Barometric Pressure for the Month of August 2019 .....	31
Figure 26. Barometric Pressure for the Month of September 2019.....	32
Figure 27. Barometric Pressure for the Month of October 2019 .....	32
Figure 28. Barometric Pressure for the Month of November 2019 .....	33
Figure 29. Barometric Pressure for the Month of December 2019.....	33

Figure 30. Daily Mean Relative Humidity at Brookhaven National Laboratory for 2019.....	34
Figure 31. Minimum Daily Humidity at Brookhaven National Laboratory for 2019 .....	35
Figure 32. Maximum Daily Humidity at Brookhaven National Laboratory for 2019.....	35
Figure 33. Relative Humidity for the Month of January 2019 .....	36
Figure 34. Relative Humidity for the Month of February 2019 .....	36
Figure 35. Relative Humidity for the Month of March 2019 .....	37
Figure 36. Relative Humidity for the Month of April 2019 .....	37
Figure 37. Relative Humidity for the Month of May 2019.....	38
Figure 38. Relative Humidity for the Month of June 2019.....	38
Figure 39. Relative Humidity for the Month of July 2019 .....	39
Figure 40. Relative Humidity for the Month of August 2019 .....	39
Figure 41. Relative Humidity for the Month of September 2019.....	40
Figure 42. Relative Humidity for the Month of October 2019 .....	40
Figure 43. Relative Humidity for the Month of November 2019 .....	41
Figure 44. Relative Humidity for the Month of December 2019 .....	41
Figure 45. Daily Rainfall Totals at Brookhaven National Laboratory for 2019.....	42
Figure 46. Historic Rainfall Totals at Brookhaven National Laboratory from 1949 to present.....	43
Figure 47. Daily Rainfall for the Month of January 2019 .....	44
Figure 48. Daily Rainfall for the Month of February 2019 .....	44
Figure 49. Daily Rainfall for the Month of March 2019 .....	45
Figure 50. Daily Rainfall for the Month of April 2019 .....	45
Figure 51. Daily Rainfall for the Month of May 2019 .....	46
Figure 52. Daily Rainfall for the Month of June 2019 .....	46
Figure 53. Daily Rainfall for the Month of July 2019 .....	47
Figure 54. Daily Rainfall for the Month of August 2019 .....	47
Figure 55. Daily Rainfall for the Month of September 2019.....	48
Figure 56. Daily Rainfall for the Month of October 2019.....	48
Figure 57. Daily Rainfall for the Month of November 2019.....	49
Figure 58. Daily Rainfall for the Month of December 2019 .....	49
Figure 59. Average Daily Wind Speed (m/s) at the 10-meter, 50-meter and 85-meter heights at Brookhaven National Laboratory for 2019 .....	54

Figure 60. Historic Annual One-hour Wind Roses for the Years 1994 to 2019 from the 85m level.....	55
Figure 61. Historic Annual One-hour Wind Roses for the Years 1994 to 2019 from the 10m level.....	55
Figure 62. Annual One-hour Wind Roses for the Year 2019 from the 85m level.....	56
Figure 63. Annual One-hour Wind Roses for the Year 2019 from the 50m level.....	56
Figure 64. Annual One-hour Wind Roses for the Year 2019 from the 10m level.....	57
Figure 65. One-hour Wind Roses for the Month of January 2019 from the 85m level.....	58
Figure 66. One-hour Wind Roses for the Month of January 2019 from the 50m level.....	58
Figure 67. One-hour Wind Roses for the Month of January 2019 from the 10m level.....	59
Figure 68. One-hour Wind Roses for the Month of February 2019 from the 85m level.....	60
Figure 69. One-hour Wind Roses for the Month of February 2019 from the 50m level.....	60
Figure 70. One-hour Wind Roses for the Month of February 2019 from the 50m level.....	61
Figure 71. One-hour Wind Roses for the Month of March 2019 from the 85m level.....	62
Figure 72. One-hour Wind Roses for the Month of March 2019 from the 50m level.....	62
Figure 73. One-hour Wind Roses for the Month of March 2019 from the 10m level.....	63
Figure 74. One-hour Wind Roses for the Month of April 2019 from the 85m level.....	64
Figure 75. One-hour Wind Roses for the Month of April 2019 from the 50m level.....	64
Figure 76. One-hour Wind Roses for the Month of April 2019 from the 10m level.....	65
Figure 77. One-hour Wind Roses for the Month of May 2019 from the 85m level.....	66
Figure 78. One-hour Wind Roses for the Month of May 2019 from the 50m level.....	66
Figure 79. One-hour Wind Roses for the Month of May 2019 from the 10m level.....	67
Figure 80. One-hour Wind Roses for the Month of June 2019 from the 85m level.....	68
Figure 81. One-hour Wind Roses for the Month of June 2019 from the 50m level.....	68
Figure 82. One-hour Wind Roses for the Month of June 2019 from the 10m level.....	69
Figure 83. One-hour Wind Roses for the Month of July 2019 from the 85m level.....	70
Figure 84. One-hour Wind Roses for the Month of July 2019 from the 50m level.....	70
Figure 85. One-hour Wind Roses for the Month of July 2019 from the 10m level.....	71
Figure 86. One-hour Wind Roses for the Month of August 2019 from the 85m level.....	72
Figure 87. One-hour Wind Roses for the Month of August 2019 from the 50m level.....	72
Figure 88. One-hour Wind Roses for the Month of August 2019 from the 10m level.....	73
Figure 89. One-hour Wind Roses for the Month of September 2019 from the 85m level .....	74

Figure 90. One-hour Wind Roses for the Month of September 2019 from the 50m level (station out of service 9-1 thru 9-20) .....	74
Figure 91. One-hour Wind Roses for the Month of September 2019 from the 10m level .....	75
Figure 92. One-hour Wind Roses for the Month of October 2019 from the 85m level .....	76
Figure 93. One-hour Wind Roses for the Month of October 2019 from the 50m level .....	76
Figure 94. One-hour Wind Roses for the Month of October 2019 from the 10m level .....	77
Figure 95. One-hour Wind Roses for the Month of November 2019 from the 85m level .....	78
Figure 96. One-hour Wind Roses for the Month of November 2019 from the 50m level .....	78
Figure 97. One-hour Wind Roses for the Month of November 2019 from the 10m level .....	79
Figure 98. One-hour Wind Roses for the Month of December 2019 from the 85m level.....	80
Figure 99. One-hour Wind Roses for the Month of December 2019 from the 50m level.....	80
Figure 100. One-hour Wind Roses for the Month of December 2019 from the 10m level.....	81
Figure 101. Wind Speed for the Month of January 2019 .....	82
Figure 102. Wind Gust data for the Month of January 2019 .....	82
Figure 103. Wind Speed for the Month of February 2019 .....	83
Figure 104. Wind Gust data for the Month of February 2019 .....	83
Figure 105. Wind Speed for the Month of March 2019 .....	84
Figure 106. Wind Gust data for the Month of March 2019 .....	84
Figure 107. Wind Speed for the Month of April 2019 .....	85
Figure 108. Wind Gust data for the Month of April 2019 .....	85
Figure 109. Wind Speed for the Month of May 2019.....	86
Figure 110. Wind Gust data for the Month of May 2019 .....	86
Figure 111. Wind Speed for the Month of June 2019.....	87
Figure 112. Wind Gust data for the Month of June 2019 .....	87
Figure 113. Wind Speed for the Month of July 2019 .....	88
Figure 114. Wind Gust data for the Month of July 2019.....	88
Figure 115. Wind Speed for the Month of August 2019 .....	89
Figure 116. Wind Gust data for the Month of August 2019.....	89
Figure 117. Wind Speed for the Month of September 2019.....	90
Figure 118. Wind Gust data for the Month of September 2019 .....	90
Figure 119. Wind Speed for the Month of October 2019 .....	91
Figure 120. Wind Gust data for the Month of October 2019.....	91
Figure 121. Wind Speed for the Month of November 2019 .....	92

Figure 122. Wind Gust data for the Month of November 2019.....	92
Figure 123. Wind Speed for the Month of December 2019 .....	93
Figure 124. Wind Gust data for the Month of December 2019 .....	93
Figure 125. Daily Peak Solar Irradiance at Brookhaven National Laboratory for 2019 .....	96
Figure 126. Average Daily Solar Irradiance at Brookhaven National Laboratory for 2019 .....	96
Figure 127. Global Horizontal Irradiance – 2019 Monthly Daily-Average .....	97
Figure 128. Average Daily Diffuse Solar Irradiance at Brookhaven National Laboratory for 2019.....	97
Figure 129. Average Daily Direct Normal Solar Irradiance at Brookhaven National Laboratory for 2019.....	98
Figure 130. Average Daily Long-wave Far Infrared Irradiance at Brookhaven National Laboratory for 2019 .....	98
Figure 131. Global Solar Radiation for the Month of January 2019 .....	101
Figure 132. Global Solar Radiation for the Month of February 2019 .....	101
Figure 133. Global Solar Radiation for the Month of March 2019 .....	102
Figure 134. Global Solar Radiation for the Month of April 2019 .....	102
Figure 135. Global Solar Radiation for the Month of May 2019 .....	103
Figure 136. Global Solar Radiation for the Month of June 2019 .....	103
Figure 137. Global Solar Radiation for the Month of July 2019.....	104
Figure 138. Global Solar Radiation for the Month of August 2019 .....	104
Figure 139. Global Solar Radiation for the Month of September 2019.....	105
Figure 140. Global Solar Radiation for the Month of October 2019.....	105
Figure 141. Global Solar Radiation for the Month of November 2019.....	106
Figure 142. Global Solar Radiation for the Month of December 2019 .....	106
Figure 143. Diffuse Solar Radiation for the Month of January 2019 .....	107
Figure 144. Diffuse Solar Radiation for the Month of February 2019 .....	107
Figure 145. Diffuse Solar Radiation for the Month of March 2019 .....	108
Figure 146. Diffuse Solar Radiation for the Month of April 2019 .....	108
Figure 147. Diffuse Solar Radiation for the Month of May 2019 .....	109
Figure 148. Diffuse Solar Radiation for the Month of June 2019 .....	109
Figure 149. Diffuse Solar Radiation for the Month of July 2019 .....	110
Figure 150. Diffuse Solar Radiation for the Month of August 2019.....	110
Figure 151. Diffuse Solar Radiation for the Month of September 2019 .....	111

Figure 152. Diffuse Solar Radiation for the Month of October 2019.....	111
Figure 153. Diffuse Solar Radiation for the Month of November 2019.....	112
Figure 154. Diffuse Solar Radiation for the Month of December 2019 .....	112
Figure 155. Direct Solar Radiation for the Month of January 2019 .....	113
Figure 156. Direct Solar Radiation for the Month of February 2019 .....	113
Figure 157. Direct Solar Radiation for the Month of March 2019 .....	114
Figure 158. Direct Solar Radiation for the Month April 2019 .....	114
Figure 159. Direct Solar Radiation for the Month May 2019.....	115
Figure 160. Direct Solar Radiation for the Month June 2019.....	115
Figure 161. Direct Solar Radiation for the Month July 2019 .....	116
Figure 162. Direct Solar Radiation for the Month August 2019 .....	116
Figure 163. Direct Solar Radiation for the Month September 2019.....	117
Figure 164. Direct Solar Radiation for the Month October 2019 .....	117
Figure 165. Direct Solar Radiation for the Month November 2019 .....	118
Figure 166. Direct Solar Radiation for the Month December 2019 .....	118
Figure 167. Long-wave Far Infrared Radiation for the Month of January 2019 .....	119
Figure 168. Long-wave Far Infrared Radiation for the Month of February 2019 .....	119
Figure 169. Long-wave Far Infrared Radiation for the Month of March 2019 .....	120
Figure 170. Long-wave Far Infrared Radiation for the Month of April 2019 .....	120
Figure 171. Long-wave Far Infrared Radiation for the Month of May 2019 .....	121
Figure 172. Long-wave Far Infrared Radiation for the Month of June 2019 .....	121
Figure 173. Long-wave Far Infrared Radiation for the Month of July 2019.....	122
Figure 174. Long-wave Far Infrared Radiation for the Month of August 2019 .....	122
Figure 175. Long-wave Far Infrared Radiation for the Month of September 2019 .....	123
Figure 176. Long-wave Far Infrared Radiation for the Month of October 2019.....	123
Figure 177. Long-wave Far Infrared Radiation for the Month of November 2019.....	124
Figure 178. Long-wave Far Infrared Radiation for the Month of December 2019 .....	124
Figure 179. Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of January 2019 .....	125
Figure 180. Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of February 2019 .....	125
Figure 181. Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of March 2019 .....	126

Figure 182. Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of April 2019 .....	126
Figure 183. Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of May 2019 .....	127
Figure 184. Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of June 2019 .....	127
Figure 185. Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of July 2019.....	128
Figure 186. Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of August 2019.....	128
Figure 187. Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of September 2019 .....	129
Figure 188. Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of October 2019.....	129
Figure 189. Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of November 2019.....	130
Figure 190. Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of December 2019 .....	130
Figure 191. Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for January 2019 .....	131
Figure 192. Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for January 2019 .....	131
Figure 193. Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for February 2019 .....	132
Figure 194. Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for February 2019 .....	132
Figure 195. Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for March 2019 .....	133
Figure 196. Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for March 2019 .....	133
Figure 197. Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for April 2019 .....	134

Figure 198. Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for April 2019 .....	134
Figure 199. Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for May 2019 .....	135
Figure 200. Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for May 2019 .....	135
Figure 201. Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for June 2019 .....	136
Figure 202. Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for June 2019 .....	136
Figure 203. Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for July 2019 .....	137
Figure 204. Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for July 2019 .....	137
Figure 205. Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for August 2019 .....	138
Figure 206. Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for August 2019 .....	138
Figure 207. Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for September 2019 .....	139
Figure 208. Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for September 2019 .....	139
Figure 209. Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for October 2019 .....	140
Figure 210. Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for October 2019 .....	140
Figure 211. Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for November 2019 .....	141
Figure 212. Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for November 2019 .....	141
Figure 213. Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for December 2019 .....	142

Figure 214. Tilted ( $23^\circ$ ) Global Solar Radiation from an SP-Lite2 Pyranometer for	
December 2019 .....	142

## **Purpose**

This document presents the meteorological data collected at Brookhaven National Laboratory (BNL) by Meteorological Services (Met Services) for the calendar year 2019. The purpose is to publicize the data sets available to emergency personnel, researchers and facility operations. Met services has been collecting data at BNL since 1949. Data from 1994 to the present is available in digital format. Data is presented in monthly plots of one-minute data. This allows the reader the ability to peruse the data for trends or anomalies that may be of interest to them. Full data sets are available to BNL personnel and to a limited degree outside researchers. The full data sets allow plotting the data on expanded time scales to obtain greater details (e.g., daily solar variability, inversions, etc.).

## **Background**

Meteorological Services (Met Services) is responsible for the maintenance, calibration, data collection and data archiving for the weather instrumentation network at Brookhaven National Laboratory. Measurements include wind speed, wind direction, temperature, rainfall, barometric pressure and relative humidity. Wind speed, wind direction and temperature are measured at 85 meters, 50 meters and at 10 meters. Rainfall, relative humidity, temperature and barometric pressure are taken at the 2 meter height. This critical data set is used for NEPA calculations, for emergency planning and operations (i.e., chemical spill or accidental release) and general research. In addition to the weather sensors, Met Services maintains a solar resource base station which measures solar radiation at BNL. Instruments include Solys-2, sun tracker equipped with a pyrheliometer (direct normal incidence radiation), a ventilated, shaded pyrgeometer (downwards long-wave, infrared radiation), a ventilated, shaded, research grade pyranometer (diffuse solar radiation) and a ventilated, unshaded, research grade pyranometer (global solar radiation). The base station also has a Sky Imager for cloud imaging and SP-Lite2 pyranometers (in-plane and horizontal) that replicate the research array sensors at the Long Island Solar Farm (LISF) and the Northeast Solar Energy Research Center (NSERC).

Meteorological data is also presented in real time via a webserver at <http://wx1.bnl.gov>. Current weather parameters are posted here. Using buttons and pull-down menus the user has a method to graph the data from several hours to several days for the past 12 months (<http://wx1.bnl.gov/graph.html>) and to see information on stability class (<http://wx1.bnl.gov/stability.php>). Graphing includes barometric pressure, temperature, wind speed, wind direction, wind gust, humidity, precipitation and solar radiation. To facilitate safe climbing of the 85-meter met tower, we also maintain a webpage with a graphical presentation of wind speed and wind gust for the past four hours (<http://wx1.bnl.gov/towerclimb.html>). This page allows workers to see the wind conditions on the tower and thereby, determine if the winds are within BNL's safe parameters (25 mph or less at the time of a climb). The page reports data from both sets of sensors on the tower, giving redundancy and a better safety margin. In addition, Met Services has a QA/QC webpage that shows all sensors over the past 24 hours

(<http://wx1.bnl.gov/graphpage.html>). This allows us to periodically (daily or greater) check the sensors and see that they are within reasonable limits and agreement.

## **Site**

Weather conditions at the BNL site have been recorded since August 1948. BNL is broadly influenced by continental and maritime weather systems. Locally, the major weather systems are modified by the Long Island Sound, the Atlantic Ocean and associated bays, which influence wind directions and humidity, and provide a moderating influence on extreme summer and winter temperatures.

BNL is a well-ventilated site, with an annual distribution of wind direction reflecting a predominance of westerly components. Prevailing winds are from the south-southwest during the summer, from the west-northwest during the winter, and about equally from these two directions during the spring and fall.

## **Instrument Towers**

### **85-meter Tower**

The 85-meter (280-ft.) meteorological tower was placed in operation in May 1981 to replace the former and original "Ace Tower" used in the first 30 operational years at BNL. The tower (Fig. 1) is located in an open field west of the majority of the Brookhaven building complex at latitude 40°52'14.84"N and longitude 72°53'20.05"W and its base is 24 m (80 ft.) above sea level and is referred to as "Tower Ten". In this document, the primary, tall tower will be called, the main or 85-meter tower to avoid confusion with the smaller, secondary 10-meter tower also in operation at the Met field.

The main tower is made of galvanized steel, is triangular in shape with 3 ft. sides and has 3 sets of 8 guy wires to keep it upright. It has an inside ladder for climbing, and two working levels with small platforms. It is difficult to mount booms and equipment or to work on this tower. Special safety belts and harnesses are required when climbing, maintaining or calibrating equipment on this tower. Sensor location names designate the approximate height of the sensors above the ground. At each location there are fully redundant sensor sets. Each set is independent of the other with unique data loggers and sensors. At locations M85 and M50 instrumentation includes; R.M. Young model 5106 Marine grade wind monitors for wind speed and direction and R.M. Young model 41342VC temperature probes. The temperature probes are protected by naturally aspirated radiation shields. Data collection is via Campbell CR1000 data loggers and transmitted to the main data computer via Campbell model RF401, 900-MHz Spread-Spectrum Radio modems.

## **10-meter Tower**

A foldable-mast, ten-meter tower is located approximately at the center of the Meteorological field. Again, fully redundant sensor sets are present. Instrumentation includes R.M. Young model 5106 Marine grade wind monitors for wind speed and direction and R.M. Young model 41342VC temperature probes. The temperature probes are protected by naturally aspirated radiation shields. Data collection is via Campbell CR1000 data loggers and transmitted to the main data computer via Campbell model RF401, 900-MHz Spread-Spectrum Radio modems.

## **2-meter pole**

At two meters (located near the 10-meter tower) sensors include; Campbell/Rotonic HC2-S3 temperature and relative humidity probes and R.M. Young model 61302V barometric pressure sensors. The T/RH probes have actively aspirated (powered fan) shields. Data collection is via Campbell CR1000 data loggers and transmitted to the main data computer via Campbell model RF401, 900-MHz Spread-Spectrum Radio modems.

Two tipping-bucket rain gauges (Novalynx model 260-2501) are maintained on the roof of building 490D. This location was chosen for available 115VAC for the heaters in the gauges required for winter use. Data collection is via Campbell CR1000 data loggers with direct network connections.

## **Solar Base Station**

Met Services maintains a platform on the roof of building 490D. This platform is used for testing of sensors and also houses the LISF research projects base station for solar irradiance measurements. Instrumentation at this location includes; a Kipp and Zonen model Solys-2 suntracker equipped with a shaded Kipp and Zonen model CGR-4 pyrgeometer for long-wave, far infrared radiation, a Kipp and Zonen model CHP-1 pyrheliometer to measure direct normal incident radiation and two Kipp and Zonen CMP-22 research grade pyranometers, one shaded and one unshaded, to record diffuse and global radiation. BNL is also home to the Long Island Solar Farm (LISF) and the Northeast Solar Energy Research Center (NSERC) where we maintain an array of sensors, including pyranometers. As a reference for the LISF sensor array, two Kipp and Zonen model SP-lite2 pyranometers are maintained, one in-plane (aka tilted global radiation) at the 27° angle of inclination for the panels at the LISF and one horizontal (global radiation). Similarly, for the NSERC sensor array, two SP-lite2 pyranometers are maintained, one in-plane at the 23° angle of inclination for the panels at the NSERC and a mating horizontally aligned unit. Data collection is via a Campbell CR3000 data loggers directly connected to the network. Additionally, a sky imaging camera is mounted on the platform and is directly connected to the network. Images from the camera are available to BNL users.

## **Calibrations**

All sensors are calibrated annually in accordance to the BNL Meteorological Instrument Network Calibration Plan (Heiser 2012). Where an instrument is sent off site for calibration a duplicate calibrated unit is available for replacement.

The calibration and maintenance frequency is based on the following hierarchy:

1. Manufacturers recommendation as stated in the instruments Operation Manual or Owner's Instruction Manual.
2. Manufacturers recommendation as stated in other communications such as a memorandum, email, or documented phone conversation.
3. Other engineering or scientific standards specifically referring to a particular type of instrument (e.g., American Nuclear Society, American National Standards Institute).
4. Met Services determination of calibration needs based on experience with the equipment and/or recommendations from other sources.

Calibration certificates are required from the companies performing calibrations and these certificates are compiled in the Instrument Calibration Notebooks. For sensors that are calibrated on site or in-situ by BNL personnel, the data taken is recorded on instrument specific data sheets and the sheets are compiled into the Instrument Calibration Notebooks. The original notebooks are maintained by the head of Met Services. Additionally, an electronic master list of equipment and the current status of each instruments calibration along with calibration coefficients is maintained on the Met Services master computer with copies available from the Head of Met Services and the Operations Officer.

## **Data Sets and Data Availability**

Meteorological sensors are checked daily and duplicate sensors inter-compared. On a monthly basis the data goes through a QA/QC process to help eliminate bad records and correct or remove any erroneous values. The post processing of the data involves visually analyzing the data in eight day increments looking for bad data points. IGOR Pro, data analysis software, is used for this purpose. Using a series of scripts it is relatively easy to remove single or multiple data points. Once the bad data is removed the operator can chose to fill in the missing points by interpolation or leave the data as "missing". The data is then saved to a file. This data is then backed up along with the raw unedited data. In addition to this we also do a comparative analysis on the "A" and "B" datasets to insure precision between the two independent systems. Data reported is generally taken from the "A" side sensors with "B" side sensors serving as backups. If data checks show the A sensors to be out of service, out of spec or questionable the data is replaced by B sensor data until the A sensor is replaced/repaired.

After the editing is complete, daily and hourly averages and sums are calculated and saved to files to be disseminated upon request. The averages are then added to a spreadsheet that includes all the past data collected here at BNL, going back as far as 1949. See; <http://www.bnl.gov/weather/MonthlyClimatology.asp>

Currently data is available as monthly, daily, hourly and minute averages. Subsets of the main data set are also available. Most requests are for a small, specific time frame, which can usually be produced in one to two days.

### **Meteorological Data Recovery for 2019**

For the year, Met Services had a 100 percent record retrieval rate, collecting all of the 526,000 records. This equates to a total of 10,512,000 fields of data that could have been collected for the year. During the course of the year, there was no significant occurrences. As required, the sensors were swapped out with calibrated units. This operation usually takes 15-20 minutes to complete. There were no other outages. Of the 10,512,000 data points available for collection the system failed to record 212 data points. This equates to 99.99% data recovery for the year.

For the Solar Base Station system there was one significant outage this year. The solar base station lost power for 8.8 hours. There was no data collected during this time. There were also a few short time losses. These totaled 4807 missing data points out of a possible 4,204,800 for the year, which represents a 99.89% data recovery rate for the year.

Tables 1 and 2 list the current year meteorological extremes and totals as well as historic extremes for BNL.

## 2019 Meteorological Data

**Table 1. 2019 Extremes and Totals<sup>a</sup>**

Highest Temperature	35.4 C° July 20 <sup>th</sup>
Lowest Temperature	-16.8 C° January 1 <sup>st</sup>
Average Yearly Temperature	10.7 C°
Annual Precipitation	52.10"
Maximum Monthly Precipitation	8.44" in December
Minimum Monthly Precipitation	1.18" in September
Maximum Daily Precipitation	2.20" on October 16 <sup>th</sup>
Maximum Hourly Rainfall	0.98" on August 11 <sup>th</sup> from 1800hrs to 1900hrs
Maximum Wind Speed (85 meters)	22.4 m/s (50.1 mph) November 1 <sup>st</sup>
Maximum Wind Gust (85 meters)	31.3 m/s (70.0 mph) November 1 <sup>st</sup>
Maximum Wind Speed (10 meters)	12.7 m/s (28.4 mph) October 16 <sup>th</sup>
Maximum Wind Gust (10 meters)	19.9 m/s (44.5 mph) February 25 <sup>th</sup>
Maximum Barometric Pressure	1035 mbar December 12 <sup>th</sup>
Lowest Barometric Pressure	990 mbar October 17 <sup>th</sup>
Lowest Relative Humidity	15% March 26 <sup>th</sup>
Heating Degree Days	5667.3
Cooling Degree Days	687.7
Average Daily Irradiance	163 W/m <sup>2</sup>

a = Measurements taken at the 2 meter height unless otherwise noted.

**Table 2. Historic Extremes<sup>a</sup>**

Highest Temperature	38.1 C (100.5 F) July 21 1991 & July 22, 1957
Lowest Temperature	-31.1 C (-23 F) January 22, 1961
Average Yearly Temperature	10.3 C (50.5 F)
Coldest Year	1967 (Avg. Temp. = 8.6 C / 47.5 F)
Warmest Year	2012 (Avg. Temp. = 12.3 C / 54.3 F)
Greatest Daily Temperature Range	31.4 C (56.5 F)
Least Daily Temperature Range	0.3 C / 0.5 F
Maximum Annual Degree Days	6753 for 1967
Maximum Monthly Degree Days	1414 in January 1977
Average Annual Precipitation	48.93"
Maximum Annual Precipitation	68.66" in 1989
Minimum Annual Precipitation	34.35" in 1965
Maximum Monthly Precipitation	22.14" in October 2005
Minimum Monthly Precipitation	Trace in June 1949, 0.18" October 1963
Maximum Daily Precipitation	9.02" September 10 - 11, 1954 Hurricane Edna 9.00" October 14th, 2005
Maximum Hourly Rainfall	2.42" on August 11 <sup>th</sup> , 2018
Maximum Seasonal Snowfall	90.8" 1995-96
Minimum Seasonal Snowfall	4.5" 1997-98
Maximum Monthly Snowfall	35.8 February 2013
Maximum Daily Snowfall	19.0" February 1978
Maximum Snowfall, Single Storm	30.9" February 8-9, 2013
Longest Period Snow Cover	55 days (Dec. 26, 1947 - February 18, 1948)
Earliest Snowfall	October 17
Latest Snowfall	April 27
Peak Wind Speed	125 mph - August 31, 1954 Hurricane Carol
Lowest Barometric Pressure	960.9 mbar September 12, 1960 Hurricane Donna

a = Measurements taken at the 2 meter height unless otherwise noted

## Air Temperature

Temperature is measured using platinum resistance thermometers (PRT) at 2-meters (Campbell HC2-S3), 10-meters (R.M. Young 41342VC), 50-meters (R.M. Young 41342VC) and 85-meters (R.M. Young 41342VC) at the locations described above.

All probes are calibrated internally by BNL staff. A high quality constant temperature bath along with a reference PRT are used to perform a comparison calibration curve. The reference PRT is calibrated off-site to NIST standards. Met Services uses the comparison method of calibrating temperature sensors. The thermometer is calibrated by comparison with a reference or standard thermometer in a thermally stabilized bath. The procedure uses a four point calibration consisting of -10°C, 5°C, 20°C and 35°C. ANSI/ANS-3.11-2005 lists the air temperature minimum accuracy of 0.5°C and a minimum resolution of 0.1°C. For stability class determinations using vertical temperature differences the requirements are; a minimum accuracy of 0.1°C and a minimum resolution of 0.01°C. Meteorological data is held to the later, more stringent requirement

For platinum resistance probes and modest accuracy applications the resistance-temperature relationship can be approximated by the Callendar-Van Dusen equation as:

$$R(t) = R(0)[1 + At + Bt^2 + C(t-100)t^3]$$

Where:

t = temperature (°C),

R(t) = resistance at temperature t,

R(0) = resistance at 0°C,

and using ASTM 1137 and IEC 60751 coefficient values for a standard 100 ohm sensor having an alpha value of 0.00385;

A = 3.9083 x 10<sup>-3</sup> (°C<sup>-1</sup>),

B = -5.775 x 10<sup>-7</sup>(°C<sup>-2</sup>) and

C = -4.183 x 10<sup>-12</sup> (°C<sup>-4</sup>) [for temperatures above 0°C, C = 0]

Within the temperature range of BNLs minimum observed temperature (-31°C) and maximum observed temperature (38°C), the B and C coefficients can be ignored and approximated as zero and;

$$R(t) = R(0) + R(0) \cdot At$$

Daily average temperature for the year is presented in Figure 1. Daily minimums and maximums for the year are shown in Figure 2. Table 4 summarizes the 2 meter monthly average daily temperatures, average daily minimum and maximum temperatures and monthly extreme high and lows. Figure 3 depicts the monthly temperature means and compares them to historic means. Figure 4 presents the yearly average temperature from 1949 to present. Table 4, 5 and 6 lists the historic monthly average, average monthly maximum and average monthly minimum temperatures from 1949 to present. Monthly data plots of 1-minute data at the four met field measurement locations are presented in Figures 5 through 16.

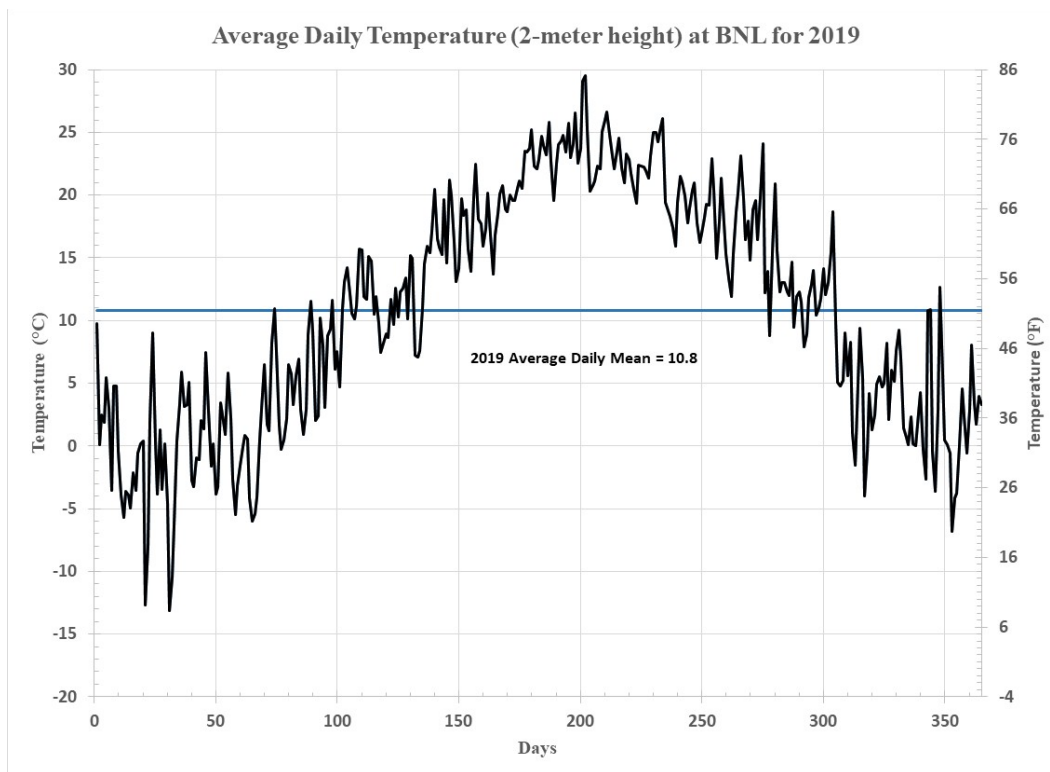


Figure 1 Average Daily Temperature taken at the 2-meter height at BNL for 2019

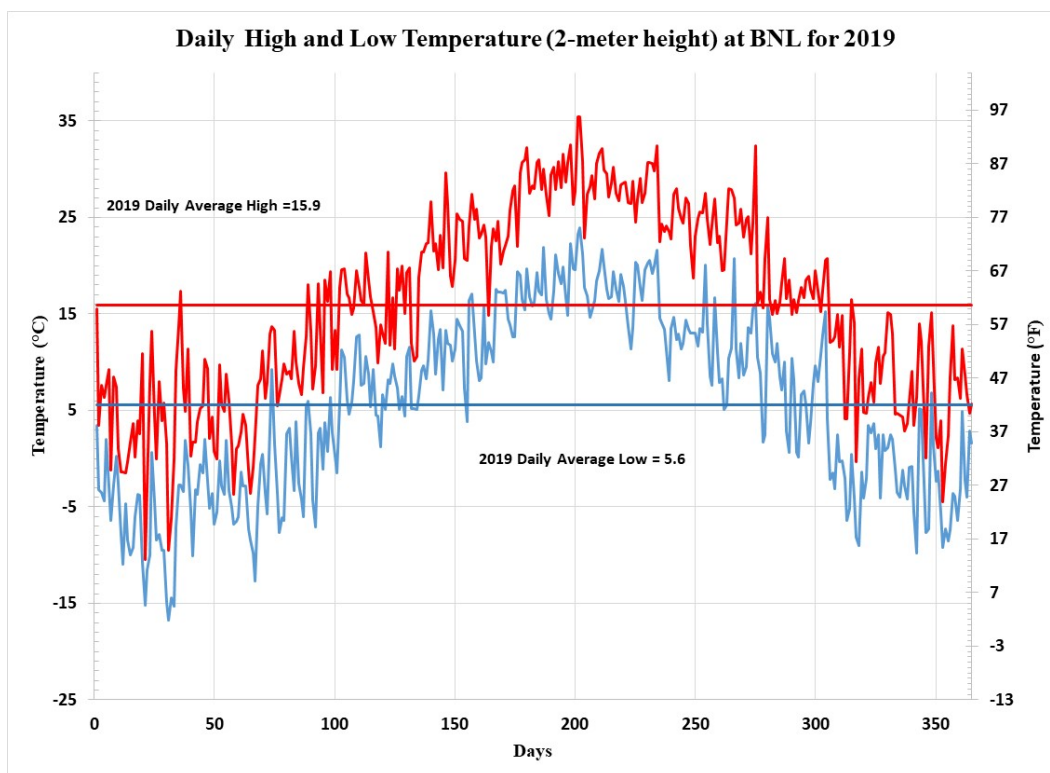


Figure 2 Daily Minimums and Maximums in Temperature taken at the 2-meter height at BNL for 2019

**Table 3. Monthly Temperature Summary**

Month	2019 Temperatures (°C) @ 2 meters						
	Average			Extremes			
	Daily Mean	Daily High	Daily Low	High	Date	Low	Date
Jan	-1.0	3.4	-6.6	15.5	Jan 1 <sup>st</sup>	-16.8	Jan 31 <sup>st</sup>
Feb	0.2	4.9	-4.2	17.4	Feb 2 <sup>nd</sup>	-15.3	Feb 5 <sup>th</sup>
Mar	2.8	7.6	-2.2	18.0	Mar 30 <sup>th</sup>	-12.7	Mar 8 <sup>th</sup>
Apr	9.9	15.1	5.0	21.3	Apr 23 <sup>th</sup>	-7.1	Apr 2 <sup>nd</sup>
May	14.0	19.2	9.3	29.6	May 26 <sup>th</sup>	4.4	May 9 <sup>th</sup>
Jun	19.4	24.5	13.9	32.2	Jun 29 <sup>th</sup>	3.8	Jun 4 <sup>th</sup>
Jul	24.0	29.4	18.4	35.4	Jul 20 <sup>th</sup>	14.5	Jul 9 <sup>th</sup>
Aug	21.8	27.3	16.4	32.4	Aug 22 <sup>nd</sup>	8.1	Aug 27 <sup>th</sup>
Sep	18.1	24.3	11.8	28.0	Sep 21 <sup>st</sup>	5.1	Sep 19 <sup>th</sup>
Oct	13.4	18.2	8.2	32.4	Oct 2 <sup>nd</sup>	0.2	Oct 20 <sup>th</sup>
Nov	4.5	10.0	-1.0	20.7	Nov 1 <sup>st</sup>	-9.0	Nov 14 <sup>th</sup>
Dec	1.9	6.3	-2.7	15.1	Dec 14 <sup>th</sup>	-9.8	Dec 8 <sup>th</sup>

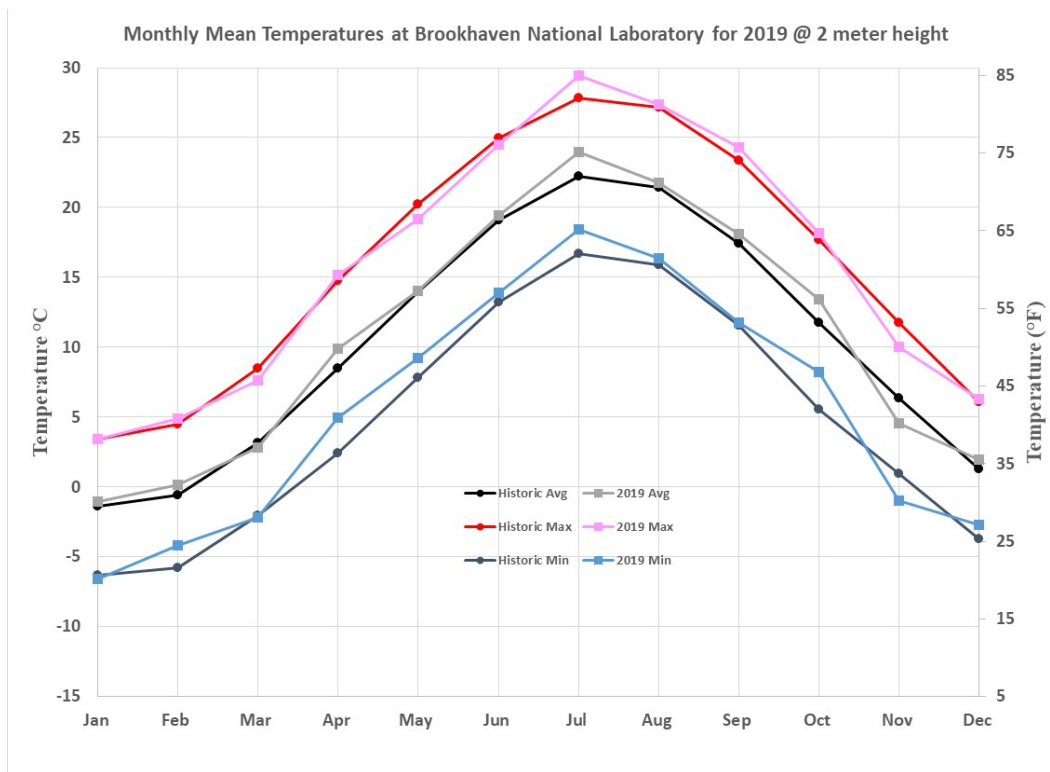


Figure 3 Monthly Mean Temperatures (°C) at Brookhaven National Laboratory for 2019

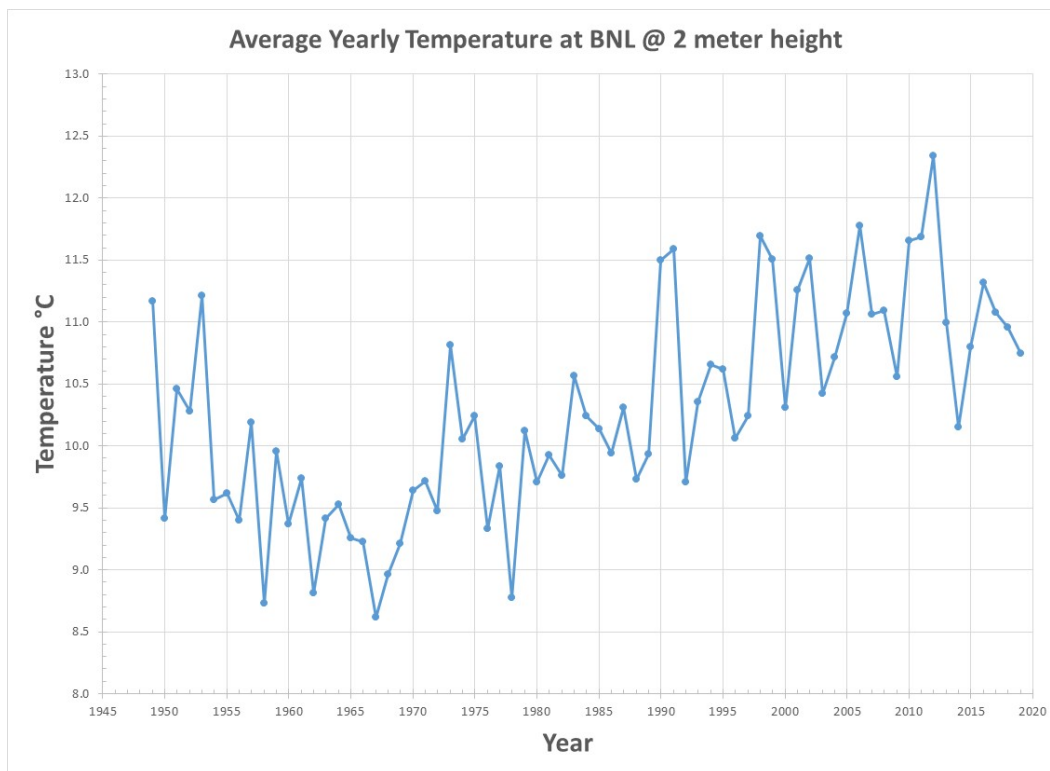


Figure 4 Average yearly temperature at Brookhaven National Laboratory – 1949 to present

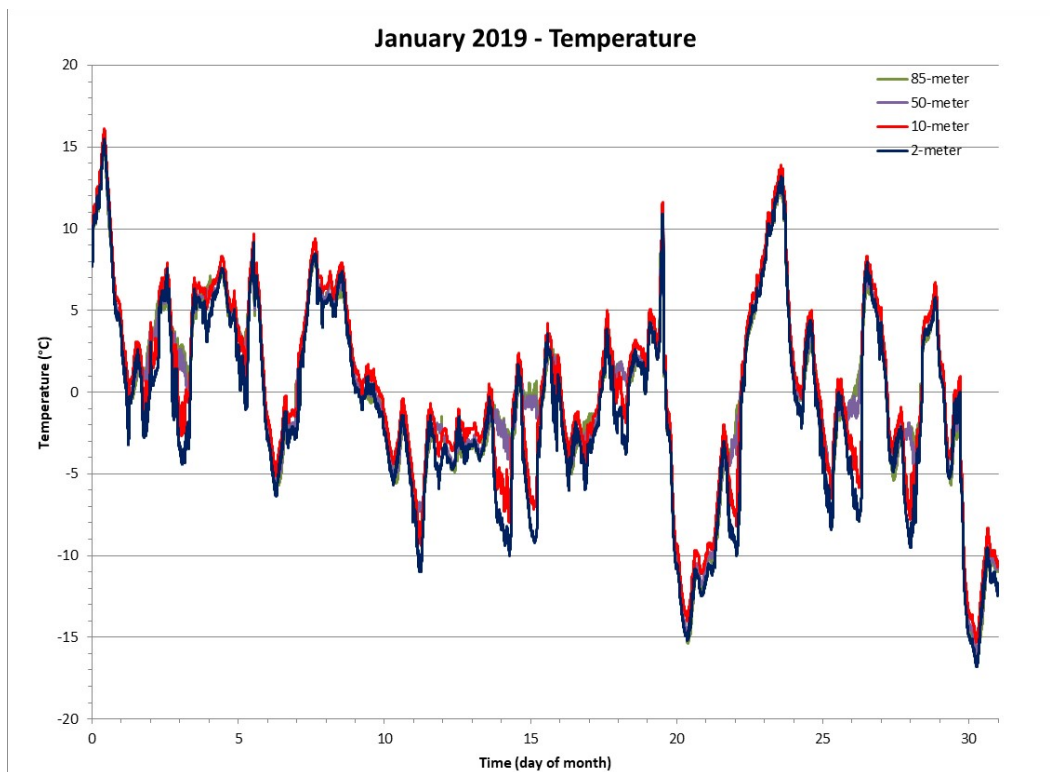


Figure 5 Air Temperature for the Month of January 2019

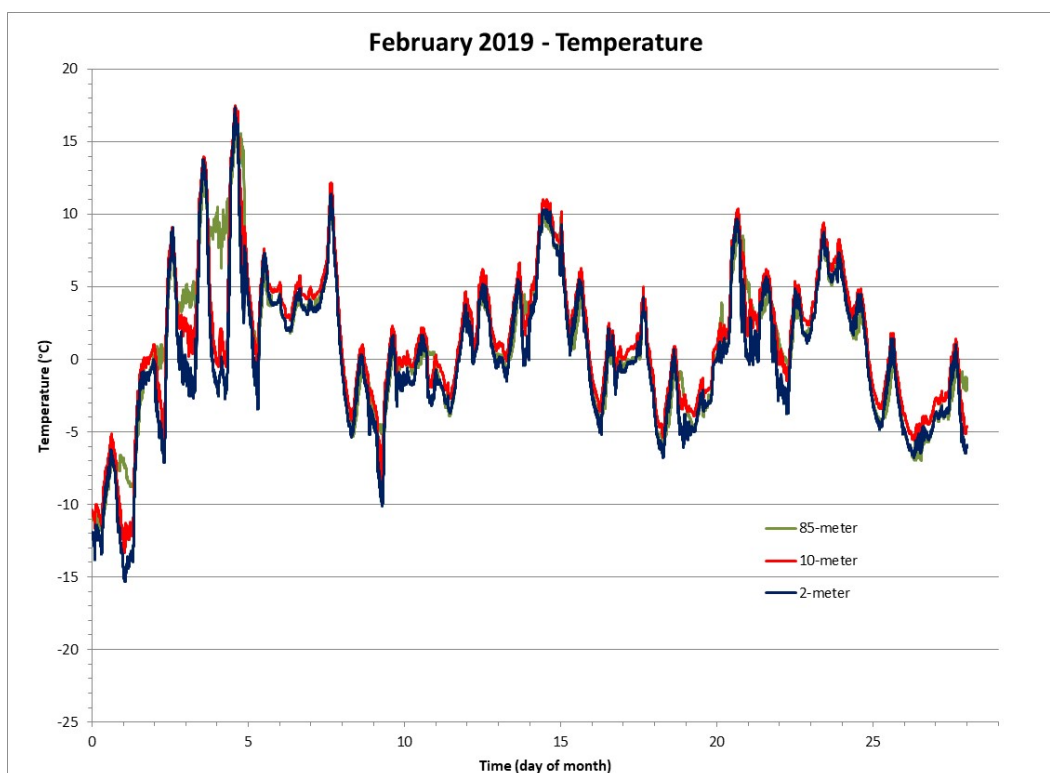


Figure 6 Air Temperature for the Month of February 2019

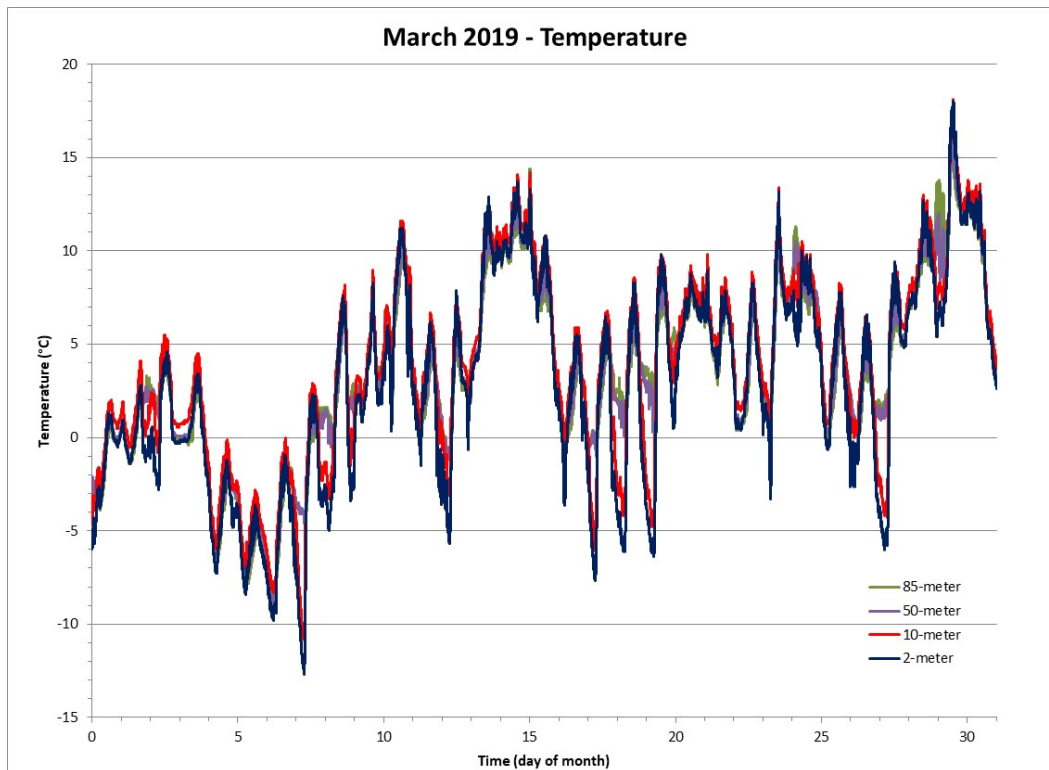


Figure 7 Air Temperature for the Month of March 2019

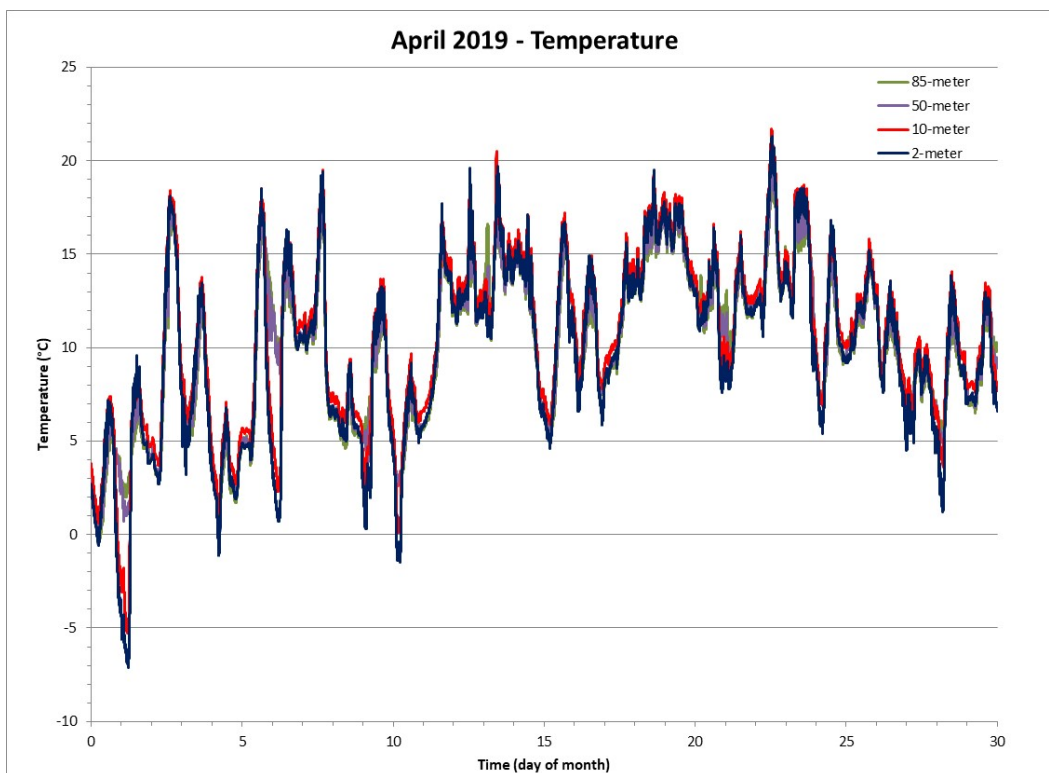


Figure 8 Air Temperature for the Month of April 2019

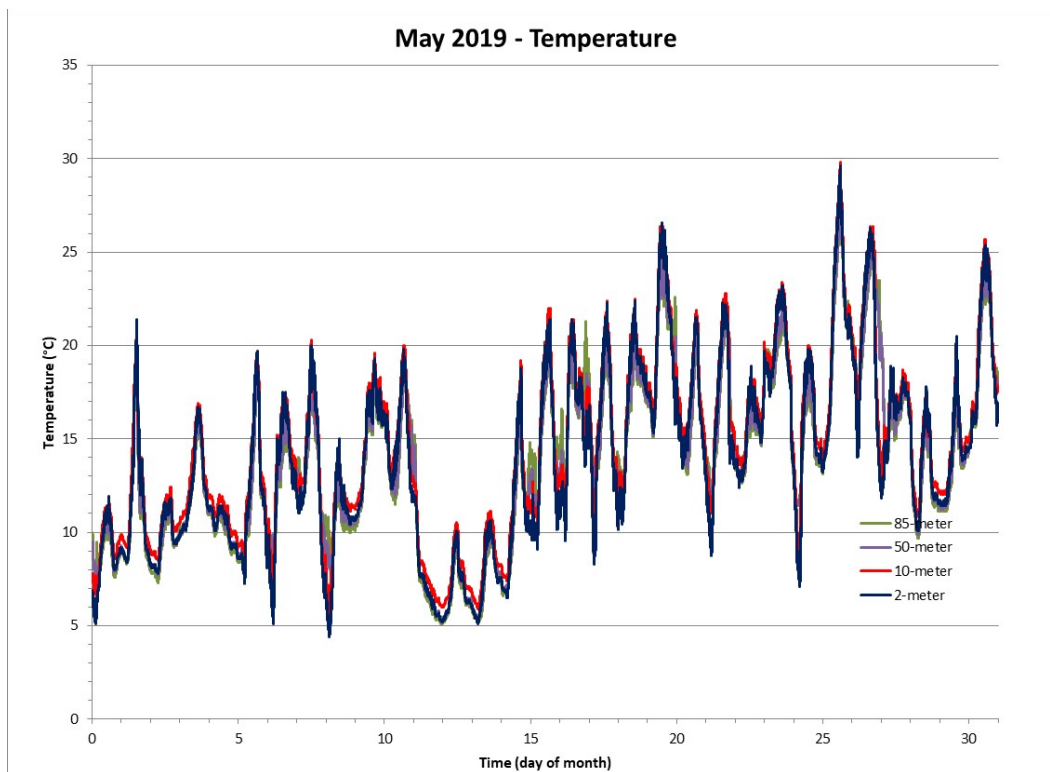


Figure 9 Air Temperature for the Month of May 2019

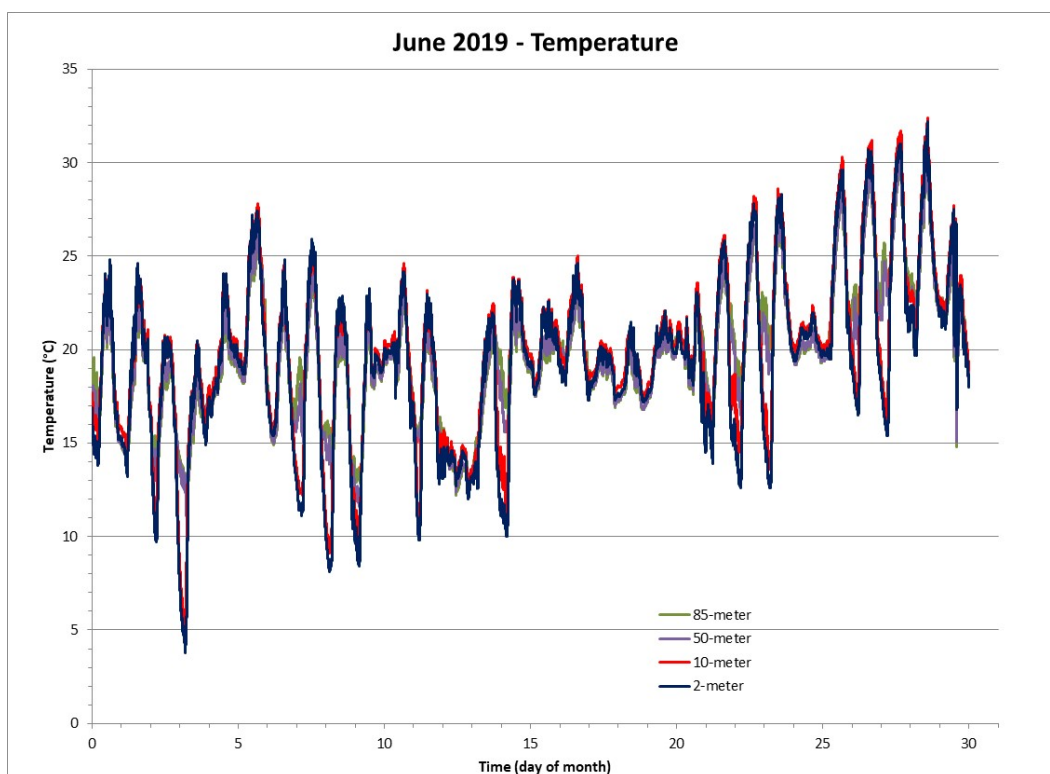


Figure 10 Air Temperature for the Month of June 2019

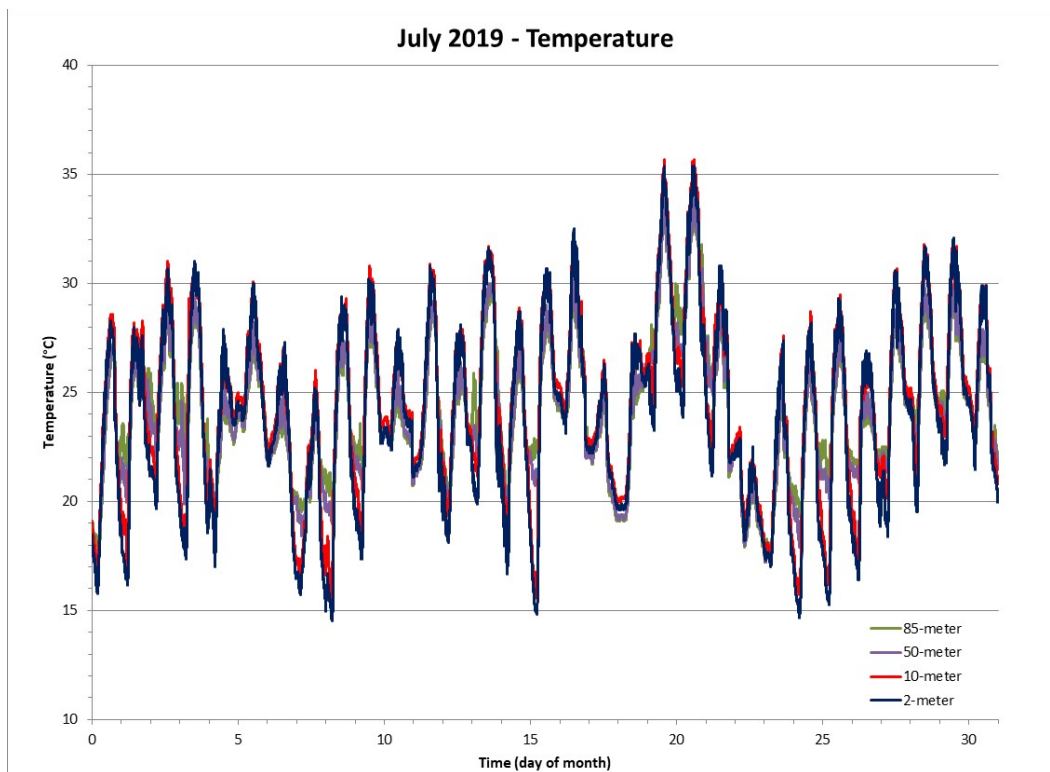


Figure 11 Air Temperature for the Month of July 2019

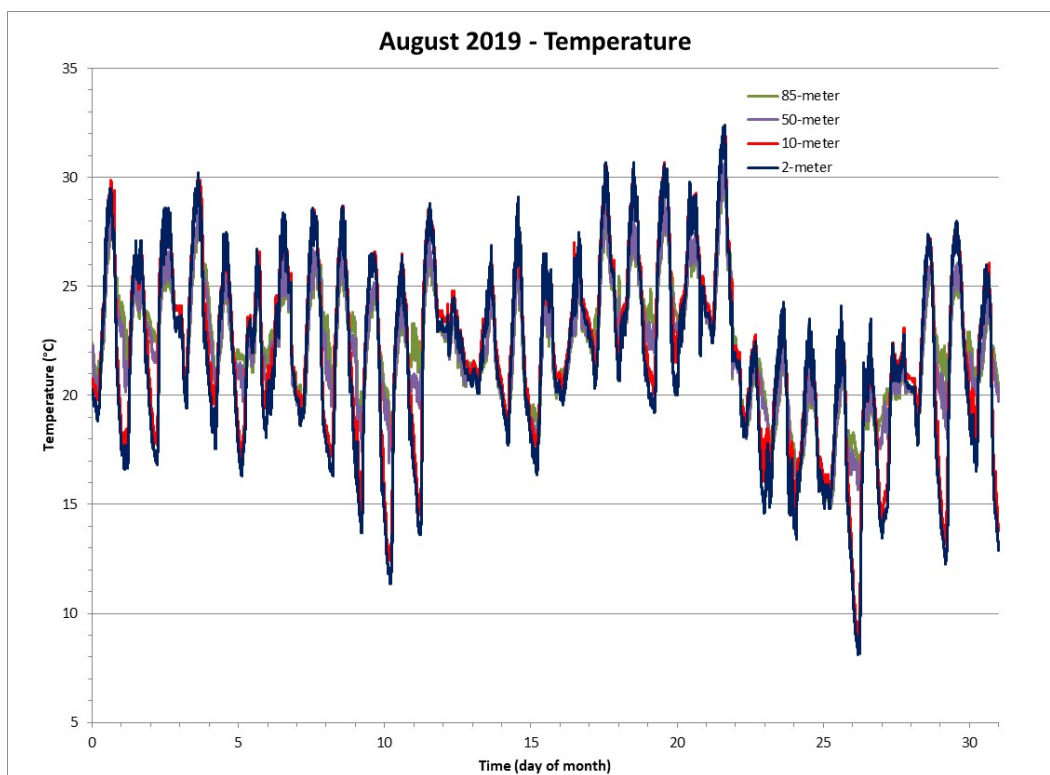


Figure 12 Air Temperature for the Month of August 2019

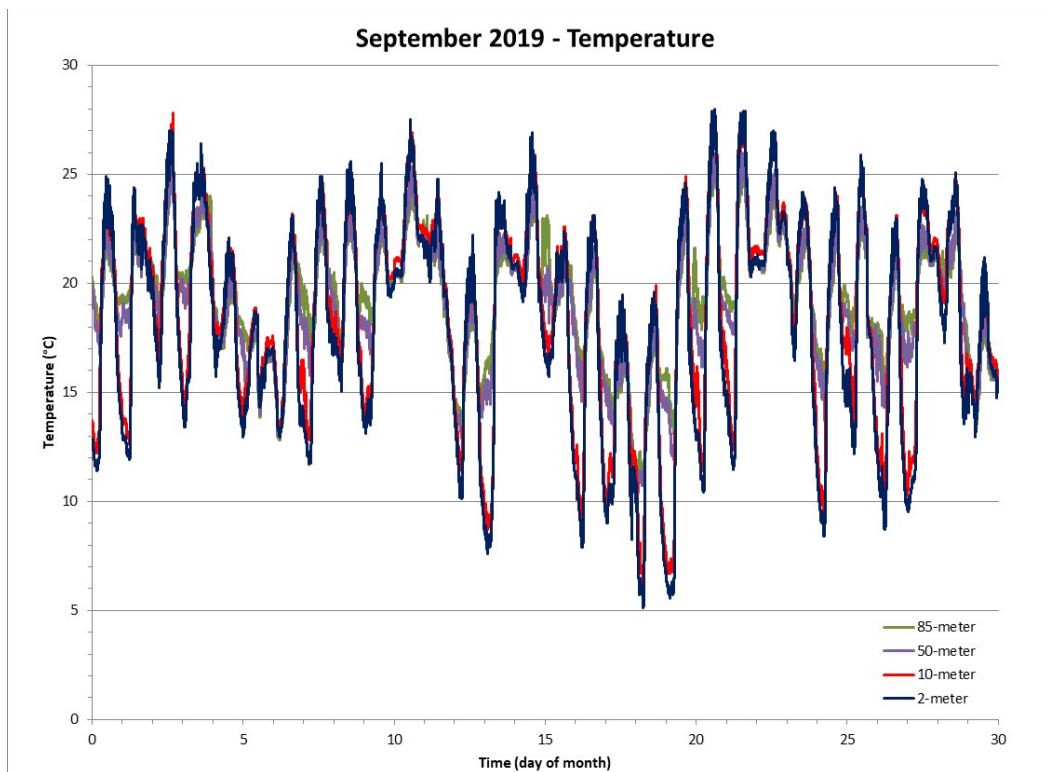


Figure 13 Air Temperature for the Month of September 2019

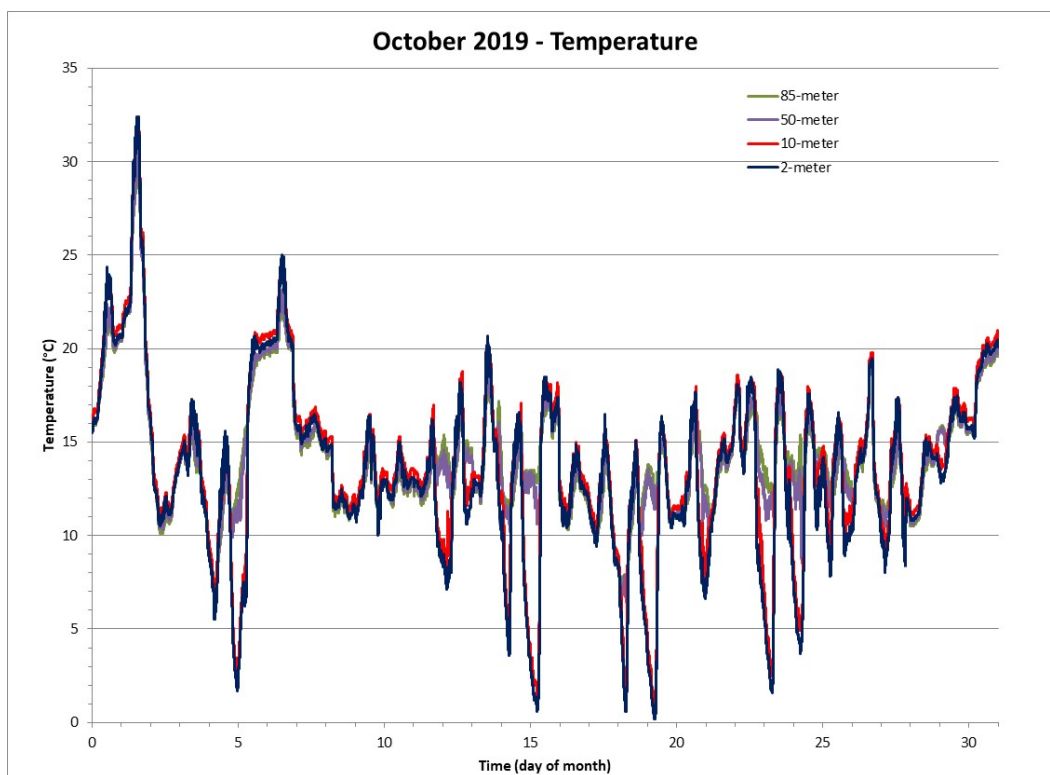


Figure 14 Air Temperature for the Month of October 2019

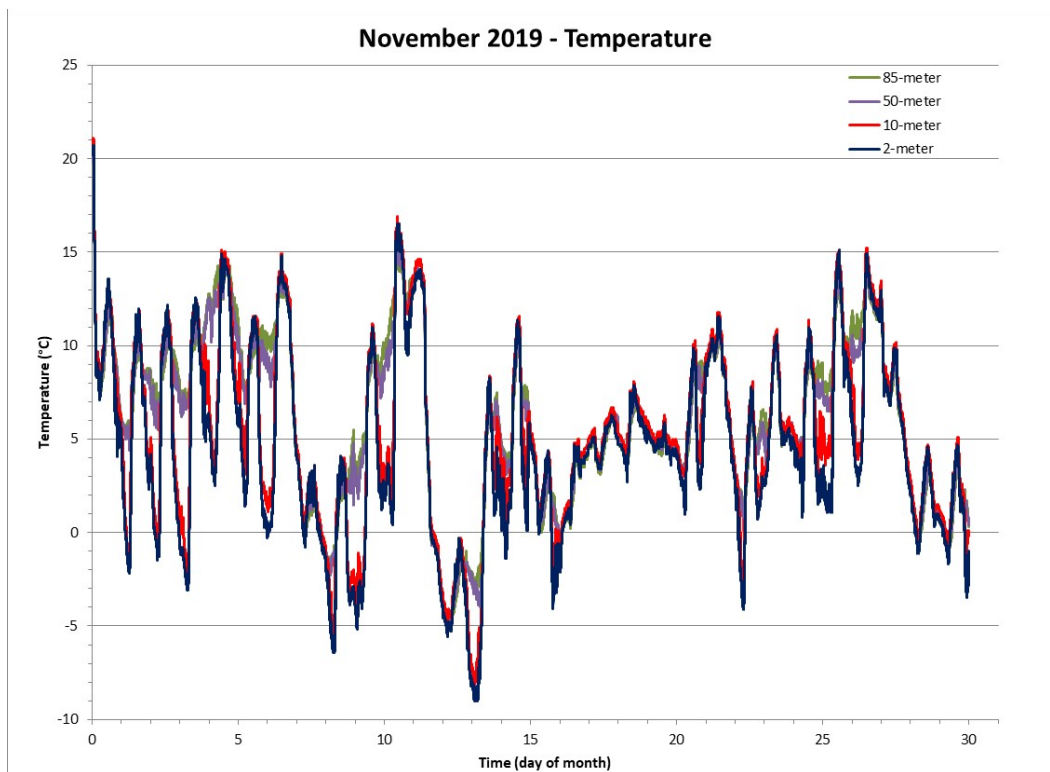


Figure 15 Air Temperature for the Month of November 2019

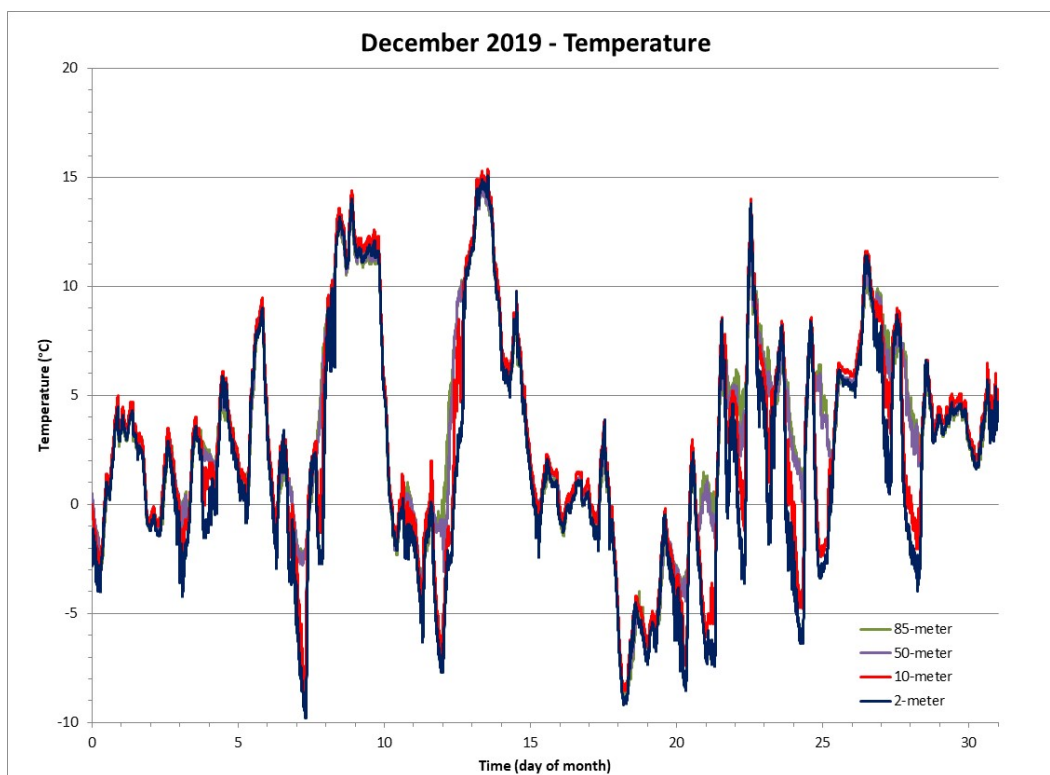


Figure 16 Air Temperature for the Month of December 2019

**Table 4. Historic Monthly Mean Temperatures (°C) for Brookhaven National Laboratory from 1949 to present (@ 2 meters)**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1949	2.3	2.0	3.6	9.5	14.3	20.1	23.3	21.9	16.2	14.1	5.6	1.2	11.2
1950	3.3	-1.7	0.6	6.3	11.9	17.9	21.1	19.7	15.4	12.1	6.3	0.0	9.4
1951	0.1	-0.1	3.2	8.6	13.9	17.6	21.5	20.3	16.9	11.9	4.4	7.2	10.5
1952	0.2	-0.1	2.7	9.2	12.8	19.8	23.5	21.2	16.7	9.8	5.9	1.6	10.3
1953	1.2	1.6	3.8	8.4	14.6	18.3	21.5	20.2	17.4	18.3	6.2	3.1	11.2
1954	-3.1	1.4	2.8	8.6	11.9	18.9	20.8	19.4	16.1	13.1	4.7	0.0	9.6
1955	-2.4	-1.1	3.1	9.2	14.7	17.3	23.8	22.1	15.8	12.4	4.5	-4.1	9.6
1956	-2.2	0.3	0.7	5.6	11.4	18.4	20.3	20.4	15.2	15.0	5.4	2.3	9.4
1957	-4.6	0.5	3.4	9.0	13.7	20.7	21.9	19.2	17.4	10.9	7.4	2.7	10.2
1958	-1.2	-3.6	2.8	8.3	11.7	16.3	22.3	20.4	16.2	10.1	5.8	-4.3	8.7
1959	-2.4	-2.4	2.1	8.4	14.6	17.8	21.3	22.1	18.3	12.2	5.9	1.6	10.0
1960	-0.8	1.2	-0.6	8.6	14.2	18.9	20.4	20.5	15.6	10.1	6.8	-2.6	9.4
1961	-4.8	-1.4	2.5	7.1	12.3	18.9	21.6	21.3	20.6	12.5	6.1	0.3	9.7
1962	-1.2	-1.2	2.9	7.6	13.3	18.6	19.3	19.4	14.8	10.3	4.0	-2.2	8.8
1963	-2.2	-3.4	4.1	8.4	12.9	19.1	21.1	19.6	15.2	13.2	8.0	-2.9	9.4
1964	-1.0	-2.6	3.0	6.6	15.1	18.1	21.8	18.8	16.4	10.4	6.0	1.7	9.5
1965	-3.6	-1.6	2.1	6.6	15.3	18.2	20.3	20.3	17.1	10.5	4.8	1.2	9.3
1966	-2.3	-1.1	3.2	5.8	11.6	18.9	22.4	21.1	16.0	9.2	6.3	-0.4	9.2
1967	0.5	-4.1	0.1	6.8	10.1	18.5	21.6	20.6	15.4	9.9	3.5	0.4	8.6
1968	-4.3	-4.0	3.1	8.2	11.8	17.8	21.9	20.6	17.8	10.1	5.8	-1.2	9.0
1969	-2.3	-1.3	1.1	8.4	13.1	17.6	20.2	22.0	16.8	10.7	4.9	-0.7	9.2
1970	-5.7	-2.0	1.4	7.9	14.2	19.1	22.4	21.9	18.1	11.6	6.8	0.2	9.6
1971	-4.4	-0.7	2.8	5.9	12.2	18.6	20.7	20.3	18.9	14.4	5.0	2.8	9.7
1972	-0.4	-1.9	2.2	6.1	13.8	18.1	22.7	20.6	18.2	8.5	4.0	1.9	9.5

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1973	-0.3	-0.8	6.1	9.6	13.0	20.8	22.4	22.2	16.7	11.3	6.6	2.2	10.8
1974	0.0	-2.5	4.1	9.7	12.9	18.4	22.2	22.1	17.1	8.8	6.3	1.6	10.1
1975	1.2	-0.8	1.7	6.6	15.4	19.2	22.9	19.1	16.1	12.3	8.5	0.8	10.2
1976	-4.6	1.6	3.6	9.8	13.1	20.1	21.1	21.2	16.4	9.7	3.2	-3.1	9.3
1977	-6.9	-1.4	5.6	8.3	14.9	18.1	22.3	22.0	18.4	10.3	6.6	0.0	9.8
1978	-3.3	-5.4	1.4	7.8	14.1	17.7	20.0	21.8	14.5	9.5	5.9	1.4	8.8
1979	-1.5	-6.5	5.4	7.4	15.2	17.1	22.6	21.9	16.8	11.5	8.4	3.3	10.1
1980	-1.2	-3.1	1.7	8.5	15.1	17.8	22.8	21.6	18.7	11.5	4.7	-1.7	9.7
1981	-6.9	0.3	2.6	9.3	14.6	20.2	23.6	21.6	17.1	9.7	6.5	0.5	9.9
1982	-5.2	-0.5	2.2	7.2	14.8	17.2	22.2	20.1	16.5	11.1	7.6	4.0	9.8
1983	0.0	-0.9	5.0	8.7	12.4	19.3	23.0	21.9	18.6	11.8	7.2	-0.3	10.6
1984	-4.0	2.8	0.7	8.4	12.8	20.1	21.4	22.1	15.6	13.0	6.1	3.9	10.2
1985	-4.2	-0.4	4.7	10.0	14.8	17.3	21.9	20.7	17.9	11.7	8.2	-0.9	10.1
1986	-1.1	-2.1	3.8	8.6	15.1	18.4	21.8	19.9	16.2	11.6	5.2	1.9	9.9
1987	-1.5	-1.5	4.4	9.7	14.4	20.2	22.9	20.2	17.2	9.6	6.7	1.5	10.3
1988	-4.2	-0.7	3.2	7.8	14.3	18.8	23.3	23.0	16.1	8.9	6.5	-0.2	9.7
1989	0.4	-1.1	3.2	7.7	14.3	20.3	21.9	21.8	17.7	11.9	5.6	-4.5	9.9
1990	2.9	1.8	4.4	8.7	13.2	19.3	22.5	22.3	17.0	14.2	7.6	4.1	11.5
1991	-0.6	1.9	5.4	10.6	16.9	20.3	22.7	22.7	16.8	12.6	7.1	2.6	11.6
1992	-0.5	0.4	2.3	7.2	13.2	18.2	20.6	20.1	17.3	10.2	5.9	1.6	9.7
1993	0.7	-2.9	1.9	9.1	15.3	19.8	23.3	22.1	17.7	10.4	5.8	1.2	10.4
1994	-4.1	-2.5	3.1	9.9	13.5	21.1	24.9	20.6	17.2	11.4	9.1	3.7	10.7
1995	2.6	-1.3	4.9	8.1	13.4	19.4	23.6	22.2	17.0	13.6	5.1	-1.1	10.6
1996	-1.6	-0.4	1.4	8.6	13.7	19.6	21.1	21.4	18.0	11.2	4.3	3.6	10.1
1997	-1.1	2.5	3.2	8.3	12.6	18.6	22.3	21.2	17.1	11.1	5.2	1.9	10.2
1998	3.3	2.9	4.8	9.2	15.6	18.7	22.4	22.4	18.7	12.2	6.7	3.4	11.7

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1999	0.1	1.3	4.1	9.1	14.8	20.7	24.6	22.1	18.7	11.1	8.6	3.1	11.5
2000	-1.8	1.1	6.1	8.2	15.1	19.6	20.6	21.4	17.3	11.8	6.0	-1.6	10.3
2001	-1.4	0.2	2.6	9.6	15.2	21.1	20.7	23.5	17.6	12.3	9.0	4.7	11.3
2002	3.0	2.3	5.4	10.8	13.8	19.3	23.4	23.3	18.7	11.5	6.2	0.6	11.5
2003	-3.2	-2.2	3.6	8.0	12.9	18.8	22.7	23.7	18.8	11.2	8.5	2.3	10.4
2004	-4.7	0.3	4.4	9.7	16.2	19.4	22.1	21.6	19.0	11.9	7.1	1.6	10.7
2005	-1.8	0.1	1.7	9.5	12.3	20.8	23.4	24.6	20.2	13.2	8.3	0.7	11.1
2006	3.0	0.2	3.8	9.9	14.9	20.2	23.8	22.4	17.1	11.7	9.2	4.9	11.8
2007	2.1	-2.2	3.4	7.9	15.3	19.6	22.4	22.2	18.7	16.1	5.8	1.3	11.1
2008	1.0	1.3	2.7	10.1	13.3	21.3	23.6	21.6	17.7	11.1	5.8	3.7	11.1
2009	-3.3	1.1	3.4	10.1	14.6	17.8	21.1	22.8	16.9	11.4	9.3	1.3	10.6
2010	-1.3	-0.3	6.8	10.7	16.2	21.3	24.6	22.7	19.7	12.8	7.1	-0.4	11.7
2011	-2.7	0.3	4.0	9.9	15.8	20.2	24.1	22.3	19.6	12.7	9.4	4.7	11.7
2012	2.2	3.2	8.0	10.7	16.4	19.6	23.3	22.7	18.3	14.0	5.2	4.4	12.3
2013	0.9	0.2	3.2	9.2	14.4	20.1	24.4	21.1	17.1	13.3	5.9	2.1	11.0
2014	-2.7	-1.8	1.3	8.3	14.8	19.3	22.0	20.3	18.0	13.3	5.6	3.3	10.1
2015	-2.6	-6.9	0.7	8.7	16.0	19.1	23.1	23.1	20.2	11.4	8.6	8.1	10.8
2016	-0.3	1.0	6.4	8.0	13.9	19.2	23.4	23.6	19.0	12.5	7.4	1.8	11.3
2017	1.4	2.8	1.8	10.7	13.8	19.3	22.1	20.6	18.7	15.0	6.7	0.0	11.1
2018	-1.8	3.2	2.6	6.7	15.8	18.8	22.8	23.5	19.5	12.4	5.6	2.3	11.0
2019	-1.0	0.2	2.8	9.9	14.0	19.4	24.0	21.8	18.1	13.4	4.5	1.9	10.7
Average	-1.4	-0.6	3.2	8.5	14.0	19.1	22.3	21.4	17.4	11.8	6.4	1.3	10.3
Max	3.3	3.2	8.0	10.8	16.9	21.3	24.9	24.6	20.6	18.3	9.4	8.1	12.3
Min	-6.9	-6.9	-0.6	5.6	10.1	16.3	19.3	18.8	14.5	8.5	3.2	-4.5	8.6

Min

Max

**Table 5. Historic Monthly Mean Maximum Temperatures (°C) for Brookhaven National Laboratory from 1949 to present (@ 2 meters)**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1949	6.6	7.1	8.4	15.0	20.4	26.0	28.7	27.9	21.7	19.9	11.5	6.9	16.7
1950	8.3	3.1	6.3	12.0	17.9	24.4	27.1	25.3	21.1	18.9	12.8	5.3	15.2
1951	5.8	6.1	8.3	15.8	21.4	23.6	27.5	26.2	23.8	17.7	10.4	7.3	16.2
1952	5.4	4.9	7.1	15.4	19.5	26.3	30.5	27.2	29.1	16.8	12.0	6.3	16.7
1953	6.2	7.0	8.7	24.1	20.2	26.1	28.6	27.0	24.7	18.8	13.4	8.6	17.8
1954	2.6	7.7	8.9	15.2	18.4	25.2	27.8	25.8	22.1	19.5	10.5	4.5	15.7
1955	1.7	4.2	8.2	14.9	22.4	23.9	29.6	27.9	22.1	18.4	9.8	1.0	15.3
1956	1.9	4.9	5.8	12.2	18.1	25.7	25.4	26.5	21.1	17.7	11.3	7.6	14.9
1957	0.4	5.6	9.2	15.5	20.6	27.2	28.6	25.8	23.4	16.9	13.0	7.9	16.2
1958	3.1	0.7	7.1	14.5	17.3	22.3	27.3	25.9	22.1	15.8	11.6	1.3	14.1
1959	2.8	3.1	7.1	14.5	21.3	23.5	26.2	27.4	24.6	17.7	11.2	6.6	15.5
1960	3.4	6.1	4.1	15.2	20.7	25.2	26.6	26.1	21.3	17.4	13.2	3.7	15.3
1961	1.1	4.7	7.7	12.4	18.3	25.1	27.1	26.7	25.9	18.7	11.3	4.7	15.3
1962	3.8	2.8	8.8	14.1	20.6	24.7	25.9	25.3	21.1	16.9	9.6	3.3	14.7
1963	3.2	2.2	9.0	15.5	20.1	25.8	27.4	25.6	20.6	20.6	12.9	1.6	15.3
1964	4.4	2.6	8.2	12.2	22.7	24.3	26.2	25.5	22.8	17.3	13.2	6.0	15.4
1965	1.5	3.2	6.9	12.8	22.6	24.8	26.6	26.0	22.4	16.3	10.6	6.5	15.0
1966	2.2	4.1	8.6	12.1	17.7	25.3	29.3	27.6	21.9	17.1	12.6	4.9	15.3
1967	5.7	2.1	5.7	12.8	16.3	24.8	26.6	25.2	22.2	17.0	8.9	6.2	14.4
1968	0.7	1.9	9.2	16.6	18.8	23.2	28.0	26.8	25.0	18.6	10.4	3.6	15.2
1969	2.1	2.2	6.3	14.6	19.9	23.8	24.9	27.6	22.9	17.5	10.3	3.6	14.7
1970	-0.7	3.9	6.3	14.1	19.9	24.4	27.4	28.1	24.1	18.1	11.9	4.5	15.2
1971	0.4	4.1	7.4	12.6	18.3	25.4	26.7	26.9	23.8	20.6	10.0	7.8	15.3

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1972	5.3	3.6	7.2	12.4	20.4	22.9	27.8	26.9	24.3	15.2	8.2	5.4	14.9
1973	5.0	3.6	11.1	15.1	18.1	25.9	28.1	28.9	23.6	18.6	11.6	7.7	16.4
1974	5.0	2.8	9.4	15.7	18.9	23.9	28.4	28.5	22.4	15.7	12.3	6.7	15.8
1975	5.9	4.2	7.4	12.7	21.9	24.4	28.1	27.3	21.6	18.4	14.3	5.8	16.0
1976	1.1	8.2	9.1	17.1	19.2	25.9	26.7	26.9	22.9	14.7	8.6	2.5	15.3
1977	-1.9	3.5	11.1	14.8	22.3	23.8	28.6	27.6	23.2	15.9	11.2	4.5	15.4
1978	1.5	0.2	6.9	13.6	19.1	24.4	25.6	26.6	21.2	16.1	11.2	6.6	14.4
1979	2.8	-2.6	10.6	13.2	20.2	22.8	28.2	26.4	22.8	16.5	13.4	7.4	15.2
1980	3.5	1.6	6.3	14.0	21.7	24.1	27.6	28.6	24.9	16.7	9.6	3.7	15.2
1981	-1.5	5.6	8.1	14.7	20.8	25.7	29.2	26.9	22.0	15.1	11.1	4.6	15.2
1982	-0.1	3.6	7.7	13.8	20.8	22.0	28.2	25.8	22.7	18.2	13.1	9.0	15.4
1983	4.8	5.7	9.7	14.3	18.0	26.7	29.6	27.8	25.6	17.4	12.7	4.8	16.4
1984	1.2	7.5	5.7	13.9	18.8	26.2	26.4	27.8	22.4	18.7	11.8	9.8	15.8
1985	0.9	4.6	10.9	16.2	21.4	23.5	28.0	26.6	24.6	18.6	12.8	4.0	16.0
1986	4.6	2.3	10.3	15.0	22.3	24.6	27.2	25.4	21.7	17.7	10.8	6.3	15.7
1987	3.3	3.6	10.7	15.4	21.0	26.1	28.6	26.2	22.8	17.1	12.7	6.5	16.2
1988	1.6	4.5	9.3	13.1	20.2	25.7	28.6	28.6	22.8	15.0	12.9	5.4	15.7
1989	6.0	3.7	8.2	14.1	20.1	25.7	27.2	27.1	23.8	18.6	10.8	0.4	15.5
1990	7.3	7.4	10.4	13.9	18.9	25.1	27.2	27.1	23.1	19.9	13.8	9.1	16.9
1991	4.9	7.5	10.3	16.4	23.7	26.7	28.8	28.2	22.7	18.4	11.9	7.9	17.3
1992	5.0	5.7	7.7	12.9	20.1	23.9	26.2	25.5	22.3	16.4	10.8	6.4	15.2
1993	5.2	3.1	6.8	14.4	22.2	25.7	29.6	27.9	22.6	16.2	12.5	6.1	16.0
1994	1.1	2.6	8.3	16.5	20.1	26.7	29.9	26.2	23.0	18.1	14.4	9.1	16.3
1995	6.6	4.2	10.4	14.3	19.3	25.1	28.5	29.1	23.4	20.2	10.1	4.2	16.3
1996	3.1	4.4	7.3	14.1	19.8	24.6	25.3	26.3	22.8	17.4	9.5	7.8	15.2
1997	3.8	7.4	8.7	14.4	18.7	25.3	28.4	26.9	23.2	17.8	10.0	6.9	15.9
1998	7.7	7.8	9.7	15.2	21.7	23.7	28.1	28.3	24.7	17.8	12.3	9.2	17.2
1999	5.6	6.6	9.7	15.9	21.7	26.8	30.7	27.1	23.9	17.7	14.1	8.1	17.3

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2000	3.2	6.2	12.2	13.5	21.1	25.0	25.8	26.3	23.1	18.0	11.1	3.2	15.7
2001	3.9	5.6	7.2	15.8	21.3	26.8	26.6	27.5	23.9	18.9	15.2	10.0	16.9
2002	7.7	8.7	10.8	16.9	19.9	25.3	29.4	28.9	24.4	16.6	10.9	5.6	17.1
2003	0.8	2.3	10.2	13.3	18.4	23.8	27.7	28.1	23.7	16.8	13.7	7.2	15.5
2004	-0.7	5.6	8.8	14.9	21.8	25.1	27.0	26.4	24.7	16.9	12.6	7.0	15.8
2005	2.7	5.6	7.3	16.5	18.0	25.9	28.5	30.0	27.3	17.6	13.7	5.4	16.6
2006	7.8	5.7	9.3	16.8	20.3	24.7	28.7	27.7	22.5	17.4	14.1	10.1	17.1
2007	6.1	2.0	9.2	13.7	22.3	25.3	27.6	27.4	24.9	21.1	11.1	5.7	16.4
2008	5.4	6.3	8.4	16.4	19.4	27.0	28.9	27.6	22.7	17.0	10.4	8.3	16.5
2009	1.0	6.1	8.9	15.8	19.8	22.9	26.3	28.1	22.4	16.6	13.2	5.3	15.6
2010	2.6	3.2	12.1	18.3	22.4	26.7	30.4	27.8	24.6	17.8	11.7	2.9	16.7
2011	0.9	5.4	8.9	14.9	21.3	25.7	29.6	27.3	24.3	17.8	14.8	9.7	16.7
2012	7.0	7.9	13.2	16.8	21.3	25.0	28.7	28.0	23.4	18.2	10.1	8.5	17.3
2013	4.9	3.7	7.4	15.1	20.6	25.3	29.0	26.6	23.3	19.3	11.4	6.7	16.1
2014	2.6	3.9	7.6	14.8	20.8	25.3	27.1	26.4	23.3	17.7	10.4	6.9	15.6
2015	1.4	-1.6	5.8	14.4	22.1	24.2	28.1	29.0	26.8	16.9	14.0	12.5	16.1
2016	4.5	6.1	11.6	14.0	19.5	25.5	28.9	29.5	24.0	18.5	13.1	6.4	16.8
2017	5.1	7.5	6.6	16.4	18.8	24.4	27.2	26.1	23.7	20.3	11.6	3.9	16.0
2018	2.7	8.2	6.7	11.9	21.6	24.2	28.3	28.2	23.9	17.0	9.8	6.7	15.8
2019	3.4	4.9	7.6	15.1	19.2	24.5	29.4	27.3	24.3	18.2	10.0	6.3	15.9
Average	3.4	4.5	8.5	14.7	20.2	25.0	27.8	27.1	23.3	17.7	11.8	6.1	15.9
Max	8.3	8.7	13.2	24.1	23.7	27.2	30.7	30.0	29.1	21.1	15.2	12.5	17.8
Min	-1.9	-2.6	4.1	11.9	16.3	22.0	24.9	25.2	20.6	14.7	8.2	0.4	14.1

Min

Max

**Table 6. Historic Monthly Mean Minimum Temperatures (°C) for Brookhaven National Laboratory from 1949 to present (@2 meters)**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1949	-1.7	-3.1	-0.8	4.3	7.9	14.1	17.9	15.8	10.7	8.3	-0.4	-4.4	5.7
1950	-1.7	-6.6	-5.1	0.7	5.9	11.4	15.2	13.9	10.0	5.0	0.0	-4.2	3.7
1951	-5.6	-5.0	-2.5	1.4	6.7	12.2	15.8	14.4	9.9	5.9	-1.3	-4.2	4.0
1952	-5.0	-5.1	-2.1	3.4	6.8	13.2	16.4	15.4	9.2	2.7	0.1	-3.2	4.3
1953	-3.3	-3.8	-1.1	2.9	9.1	11.6	14.3	13.0	10.1	4.1	-1.2	-2.6	4.4
1954	-8.1	-4.1	-3.1	1.9	5.0	12.6	13.9	13.2	10.4	6.3	-1.4	-4.6	3.5
1955	-6.7	-6.4	-2.5	3.5	7.0	10.7	18.1	16.2	9.8	6.4	-0.6	-9.2	3.9
1956	-6.3	-4.2	-4.6	-1.1	4.8	10.9	15.1	14.3	9.2	3.1	-0.3	-2.9	3.2
1957	-9.7	-4.7	-2.2	2.6	6.8	14.3	15.3	12.6	11.4	4.8	1.8	-2.3	4.2
1958	-5.5	-7.8	-1.2	2.1	6.1	10.3	17.3	14.7	10.4	4.3	0.1	-9.9	3.4
1959	-7.6	-7.7	-2.9	2.3	7.8	12.2	16.5	16.8	12.1	6.7	0.6	-3.6	4.4
1960	-5.1	-3.1	-5.1	2.0	7.5	12.6	14.4	15.0	9.9	2.8	0.4	-8.7	3.6
1961	-10.7	-7.0	-2.7	1.8	6.7	12.4	16.1	15.8	15.2	6.4	0.8	-4.7	4.2
1962	-7.5	-6.7	-2.6	1.2	6.1	12.3	12.3	13.4	8.6	3.9	-1.5	-7.6	2.7
1963	-7.7	-9.0	-1.1	1.4	5.9	12.4	15.2	13.6	9.9	5.9	3.2	-6.8	3.6
1964	-6.4	-7.9	-2.2	0.9	7.6	12.1	17.4	12.2	10.1	3.6	-1.1	-2.6	3.7
1965	-8.9	-6.1	-2.8	0.3	8.1	11.6	13.9	14.5	11.8	4.4	-0.9	-4.0	3.5
1966	-6.8	-6.4	-2.4	-0.4	5.5	12.6	15.6	14.6	10.2	1.4	0.4	-5.7	3.2
1967	-4.5	-10.0	-5.5	0.8	4.1	12.3	17.4	16.2	8.9	3.1	-1.8	-5.4	2.9
1968	-9.1	-9.8	-2.8	-0.1	5.3	12.6	15.8	14.4	10.6	6.9	1.1	-6.1	3.3
1969	-6.7	-4.9	-4.1	2.2	6.2	11.4	15.6	16.1	10.7	4.5	-0.4	-4.9	3.8
1970	-10.7	-7.9	-3.6	1.9	8.4	13.6	17.3	15.6	12.1	5.4	1.7	-4.1	4.1
1971	-9.5	-5.4	-1.9	-0.7	6.1	12.2	14.8	13.6	14.2	8.6	0.0	-2.1	4.2

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1972	-6.2	-7.5	-2.6	-0.3	6.9	13.2	17.7	13.9	12.0	1.8	-0.2	-1.6	3.9
1973	-6.0	-5.2	0.9	4.1	7.9	15.8	16.7	17.5	10.0	3.9	1.6	-2.2	5.4
1974	-5.0	-7.9	-1.3	3.7	6.9	13.2	16.0	15.4	11.9	2.1	0.2	-3.5	4.3
1975	-3.4	-5.9	-4.0	0.5	9.1	13.9	17.8	16.1	10.5	6.3	3.2	-4.8	4.9
1976	-10.4	-5.3	-1.8	2.6	6.9	14.2	15.4	15.4	9.8	4.7	-2.3	-8.6	3.4
1977	-12.2	-6.5	0.0	0.9	7.4	12.3	16.1	16.5	13.6	4.7	1.9	-4.5	4.2
1978	-8.1	-11.5	-3.9	1.9	8.9	11.0	14.4	17.0	7.7	2.9	0.5	-3.9	3.1
1979	-5.8	-10.5	-0.3	1.6	10.2	11.4	16.9	17.4	10.8	6.4	3.3	-1.0	5.1
1980	-5.8	-7.7	-2.9	2.9	8.6	11.6	18.0	17.9	12.3	6.3	-0.3	-6.9	4.5
1981	-12.3	-4.9	-3.4	4.0	8.3	14.7	18.0	15.9	12.2	4.3	2.0	-3.6	4.6
1982	-10.4	-4.6	-3.4	0.7	8.7	12.3	16.3	14.4	10.3	4.1	2.1	-1.0	4.1
1983	-4.8	-5.5	0.3	3.1	6.8	11.9	16.4	16.1	11.7	6.1	1.7	-5.3	4.9
1984	-9.3	-1.8	-4.2	2.9	6.9	13.9	16.3	16.4	8.8	7.3	0.2	-1.9	4.6
1985	-9.3	-5.4	-1.4	3.8	8.2	11.1	15.8	14.8	11.2	4.8	3.6	-5.8	4.3
1986	-6.7	-6.6	-2.7	2.1	7.8	12.2	16.4	14.5	10.8	5.4	-0.6	-2.5	4.2
1987	-6.3	-6.6	-1.9	3.9	7.8	14.4	17.2	14.1	11.5	2.2	0.7	-3.6	4.4
1988	-10.0	-5.9	-3.1	2.5	8.3	12.0	17.9	17.4	9.4	2.8	0.1	-5.8	3.8
1989	-5.2	-5.9	-2.4	1.3	8.6	14.9	16.6	16.7	11.6	5.3	0.3	-9.4	4.3
1990	-1.4	-3.8	-1.6	3.5	7.4	13.6	17.8	17.4	10.9	8.3	1.4	-0.9	6.1
1991	-6.0	-3.6	0.6	4.7	10.1	13.9	16.7	17.2	10.8	6.8	2.2	-2.6	5.9
1992	-5.9	-4.7	-3.1	1.7	6.2	12.5	15.1	14.7	12.4	3.9	1.1	-3.3	4.2
1993	-3.8	-8.9	-2.9	3.6	8.5	13.8	16.9	16.2	12.8	4.7	-1.1	-3.7	4.7
1994	-9.1	-7.7	-2.2	3.4	6.9	15.4	20.0	14.9	11.4	4.7	3.7	-1.7	5.0
1995	-1.6	-6.9	-0.6	1.8	7.5	13.8	18.7	15.3	10.7	6.9	0.2	-5.9	5.0
1996	-6.2	-5.3	-4.6	3.2	7.6	14.7	16.8	16.6	13.2	4.9	-0.9	-0.7	4.9
1997	-5.8	-2.4	-2.3	2.2	6.6	11.9	16.1	15.6	11.1	4.4	0.3	-3.1	4.6
1998	-1.2	-1.9	-0.1	3.1	9.6	13.8	16.7	16.4	12.7	6.6	1.2	-2.3	6.2
1999	-5.3	-4.0	-1.6	2.3	8.0	14.6	18.4	16.9	13.5	4.4	3.1	-1.9	5.7

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
2000	-6.9	-4.1	-0.1	2.9	9.1	14.2	15.3	16.4	11.5	5.7	0.9	-6.2	4.9
2001	-6.8	-5.1	-2.1	3.3	9.2	15.4	14.7	18.1	11.3	5.8	2.9	-0.6	5.5
2002	-1.7	-4.1	0.0	4.7	7.8	13.3	17.5	17.6	12.9	6.3	1.5	-4.4	5.9
2003	-7.2	-6.7	-2.9	2.7	6.8	13.8	17.7	19.2	13.9	5.6	3.3	-2.4	5.3
2004	-8.7	-5.0	0.2	4.6	10.6	13.8	17.2	16.8	13.3	6.8	1.6	-3.8	5.6
2005	-6.3	-5.6	1.7	2.5	6.6	15.6	18.2	19.1	13.1	8.8	2.9	-4.1	6.1
2006	-1.8	-5.3	-1.7	3.1	9.6	15.6	18.9	17.0	11.7	5.9	4.4	-0.1	6.4
2007	-2.7	-7.1	-2.6	2.2	8.4	13.9	17.3	16.9	12.6	11.2	0.5	-3.0	5.6
2008	-4.0	-4.1	-3.1	4.1	7.4	15.8	18.5	16.0	12.7	5.1	0.8	-1.7	5.6
2009	-7.9	-3.9	-1.9	4.2	9.6	13.8	15.8	18.1	11.2	6.0	4.8	-3.1	5.6
2010	-5.8	-4.2	1.5	5.5	10.0	15.9	19.1	17.3	14.6	7.3	1.9	-4.2	6.6
2011	-7.3	-5.4	-0.8	5.2	10.9	14.9	18.6	17.4	15.8	7.8	4.0	-1.5	6.7
2012	-3.2	-2.6	3.0	3.8	11.9	13.9	18.5	17.4	12.7	9.4	0.0	-0.1	7.1
2013	-4.5	-3.9	-1.4	3.4	8.3	15.0	20.3	15.3	10.8	7.0	0.1	-2.6	5.7
2014	-8.7	-7.7	-5.1	1.7	8.7	13.4	17.3	14.5	12.3	8.3	0.5	-0.5	4.6
2015	-7.5	-13.6	-4.4	2.1	10.0	14.1	18.1	17.0	14.3	5.5	2.7	3.7	5.2
2016	-5.3	-4.8	1.2	1.9	8.6	13.0	18.1	17.8	13.9	7.0	1.8	-3.1	5.8
2017	-2.5	-2.7	-2.9	5.3	8.9	13.7	17.2	15.4	14.2	10.0	1.0	-4.3	6.1
2018	-6.8	-1.7	-1.4	1.2	10.5	13.0	17.4	19.0	15.7	7.4	0.9	-2.3	6.1
2019	-6.6	-4.2	-2.2	5.0	9.3	13.9	18.4	16.4	11.8	8.2	-1.0	-2.7	5.5
Average	-6.3	-5.8	-2.1	2.5	7.8	13.2	16.7	15.9	11.6	5.6	0.9	-3.7	4.7
Max	-1.2	-1.7	3.0	5.5	11.9	15.9	20.3	19.2	15.8	11.2	4.8	3.7	7.1
Min	-12.3	-13.6	-5.5	-1.1	4.1	10.3	12.3	12.2	7.7	1.4	-2.3	-9.9	2.7

Min

Max

## Barometric Pressure

Barometric pressure is measured at the 2-meter level. The pressure sensors are connected to R.M. Young model 61002 pressure ports to reduce errors due to blowing winds. The sensors are sent off-site for calibration. Average daily pressure for 2019 is plotted in Figure 17. The lowest pressure, 990 mbar, occurred on October 17<sup>th</sup>. Monthly data plots of the 1-minute data for pressure are presented in Figures 18 through 29.

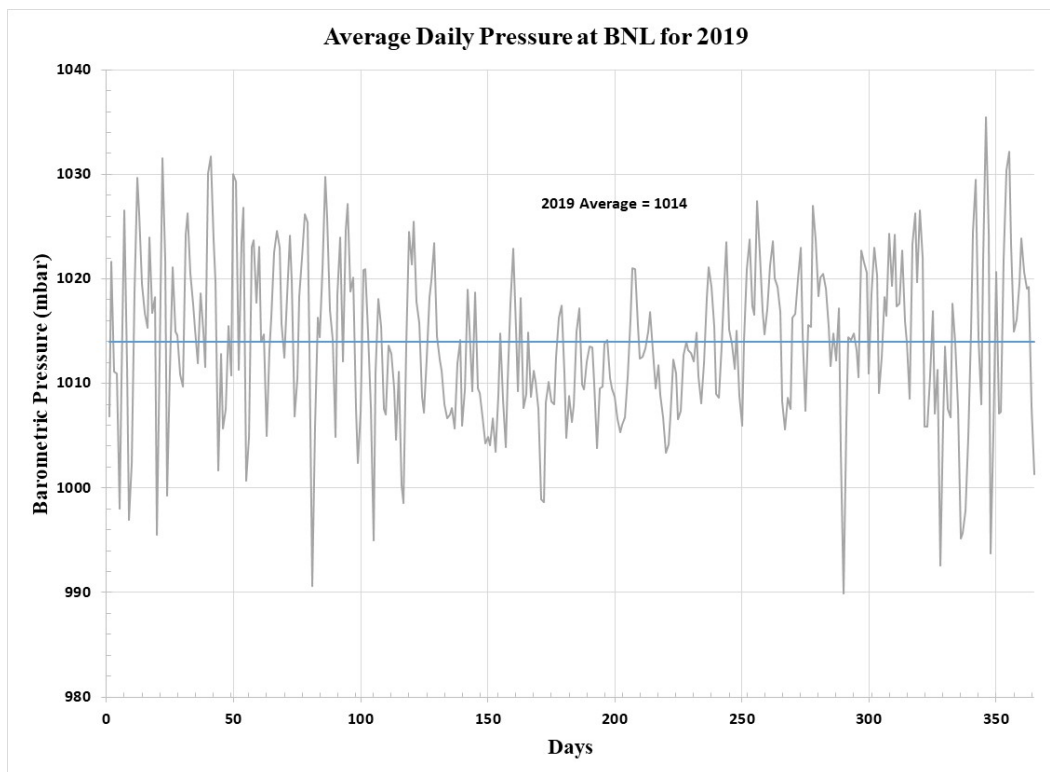


Figure 17 Average Daily Barometric Pressure at Brookhaven National Laboratory for 2019

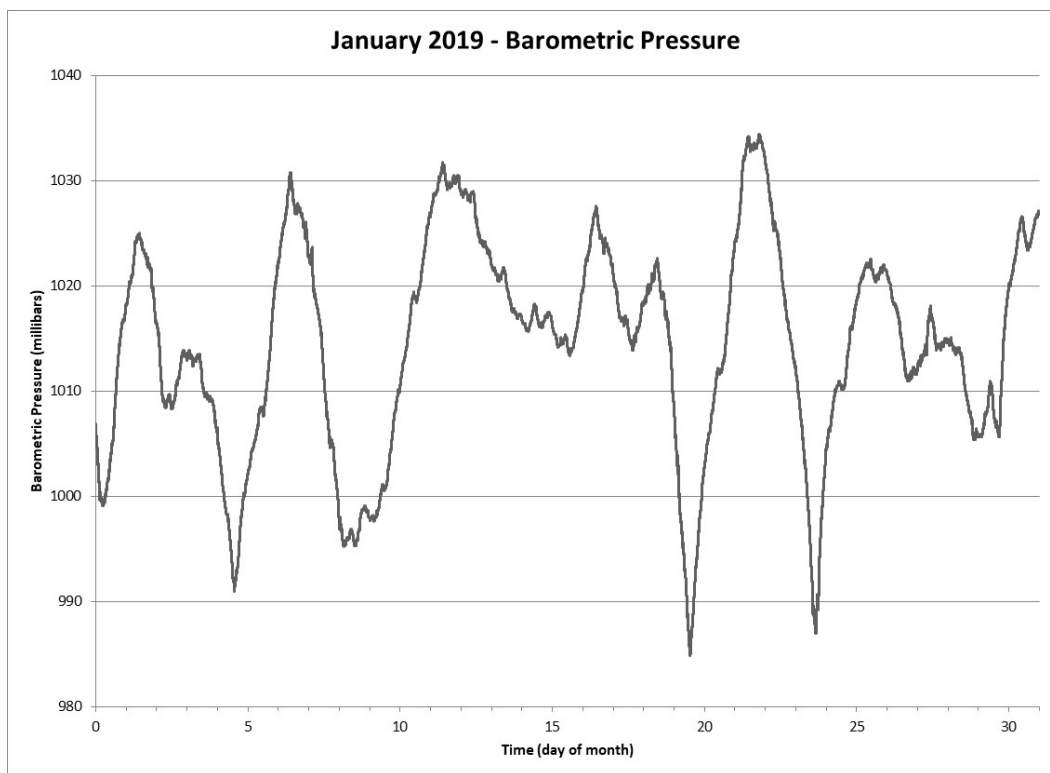


Figure 18 Barometric Pressure for the Month of January 2019

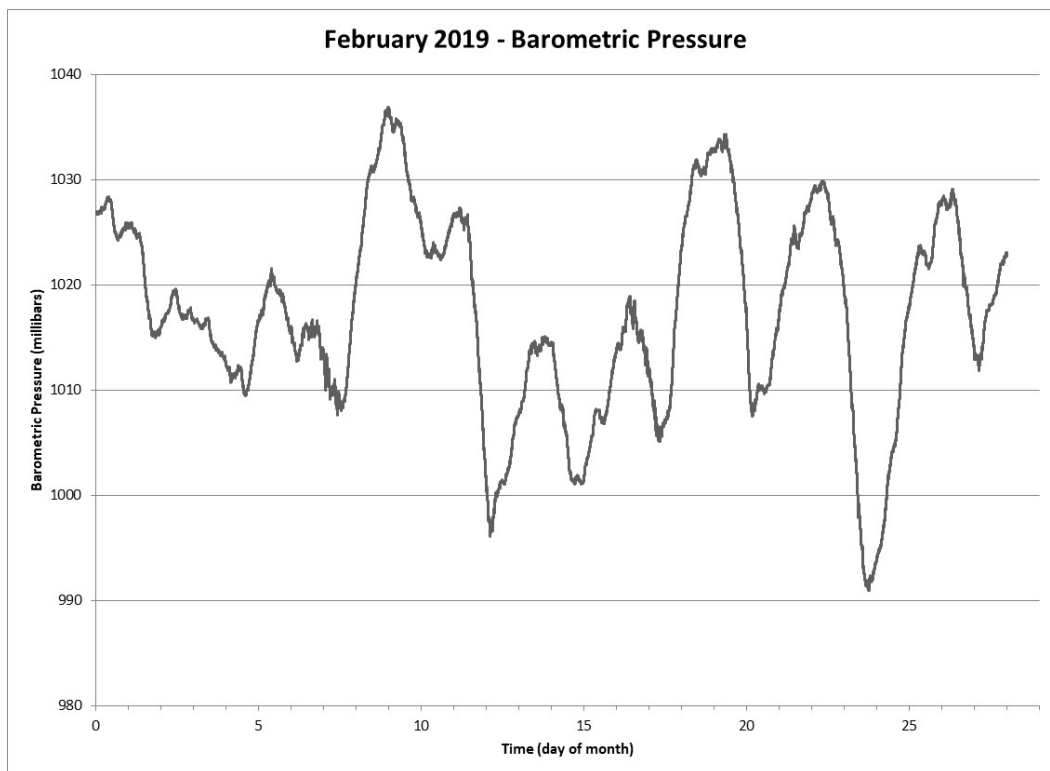


Figure 19 Barometric Pressure for the Month of February 2019

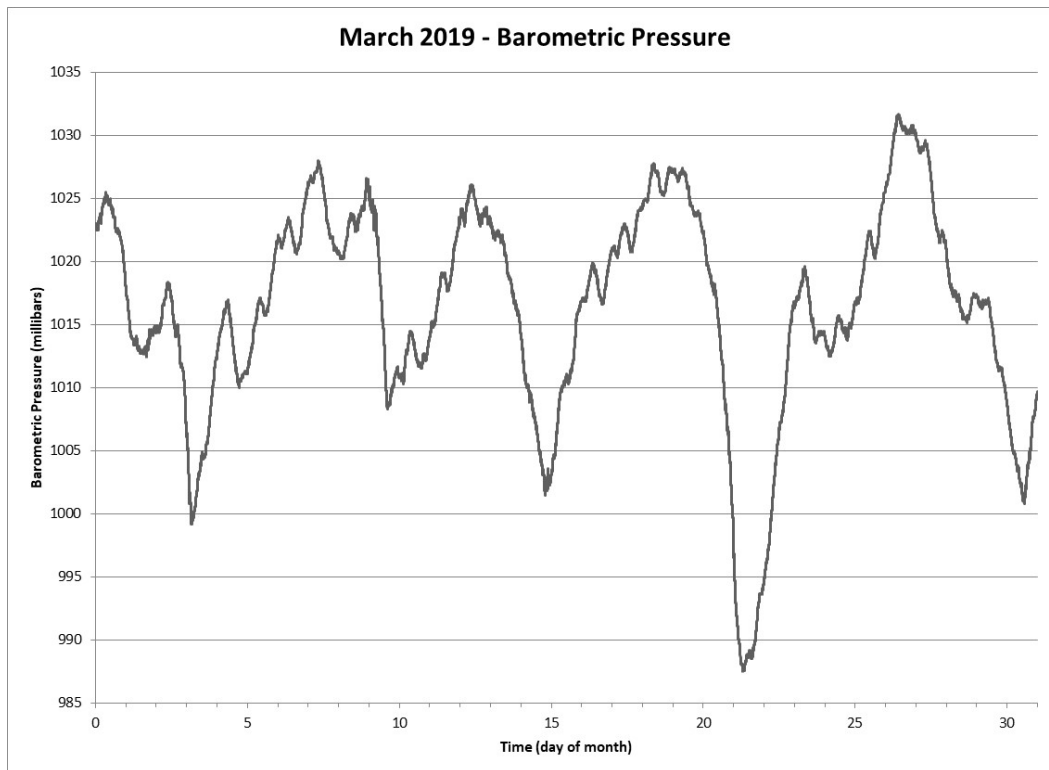


Figure 20 Barometric Pressure for the Month of March 2019

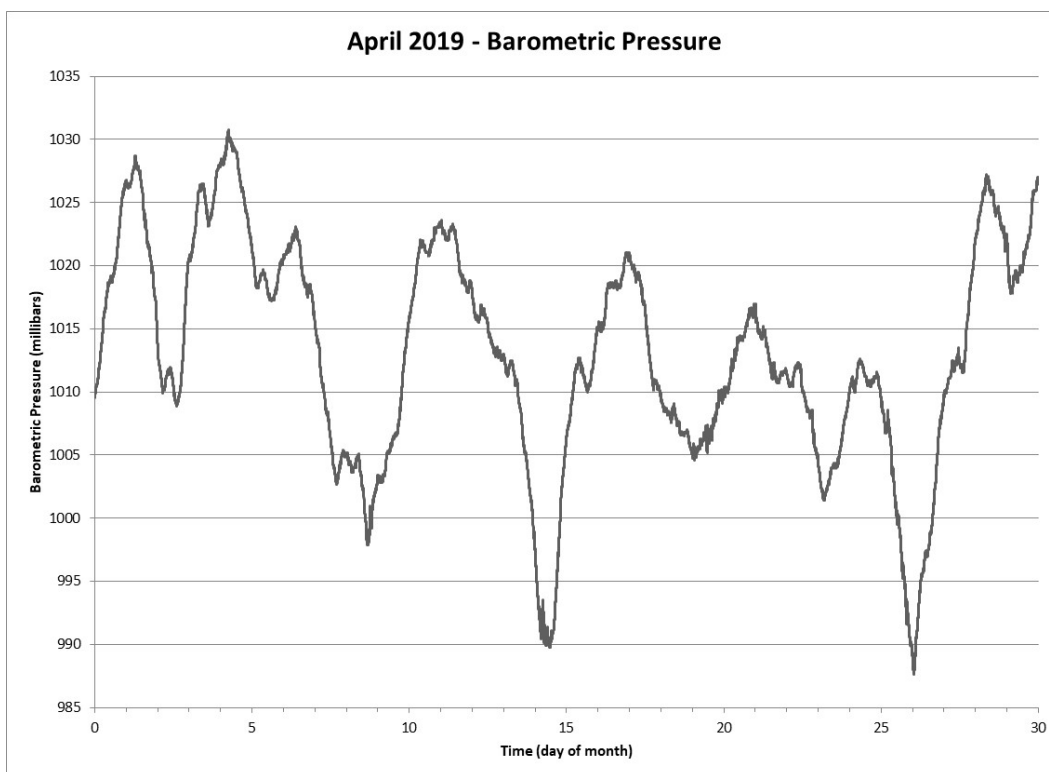


Figure 21 Barometric Pressure for the Month of April 2019

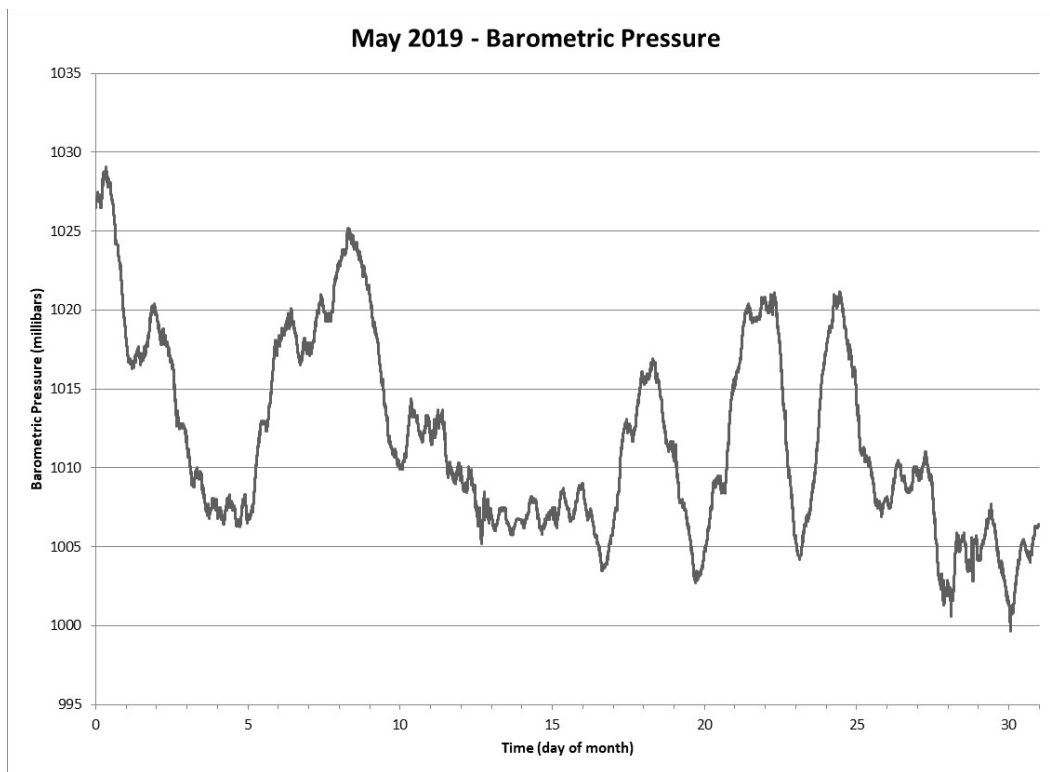


Figure 22 Barometric Pressure for the Month of May 2019

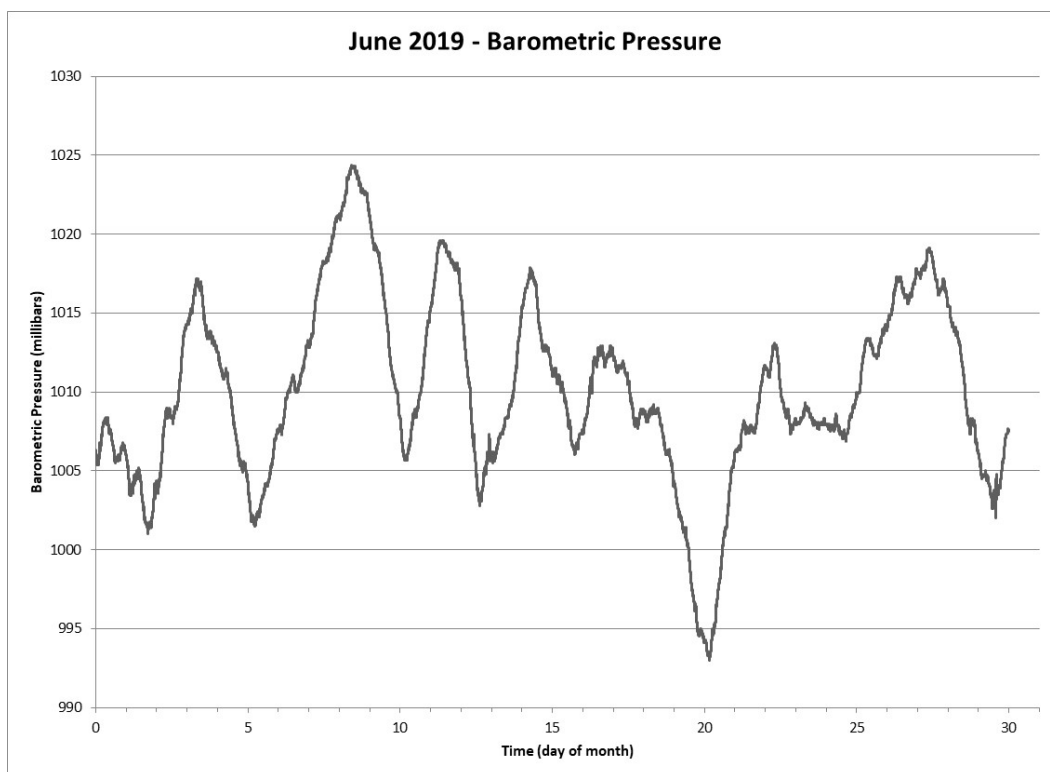


Figure 23 Barometric Pressure for the Month of June 2019

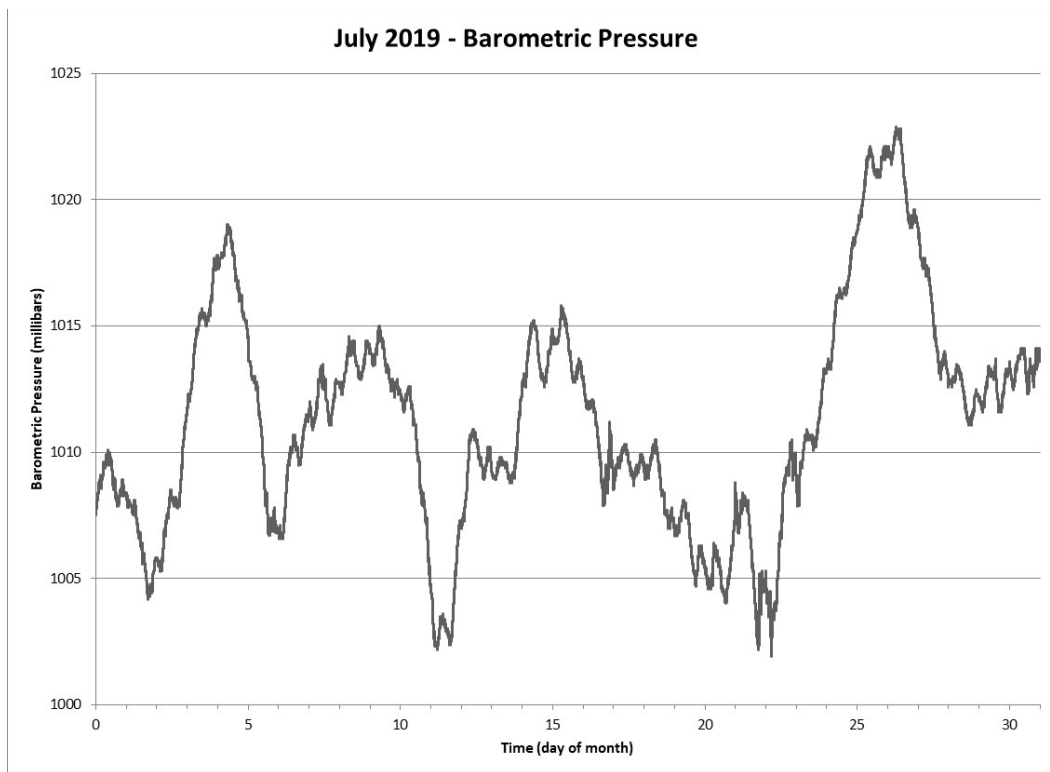


Figure 24 Barometric Pressure for the Month of July 2019

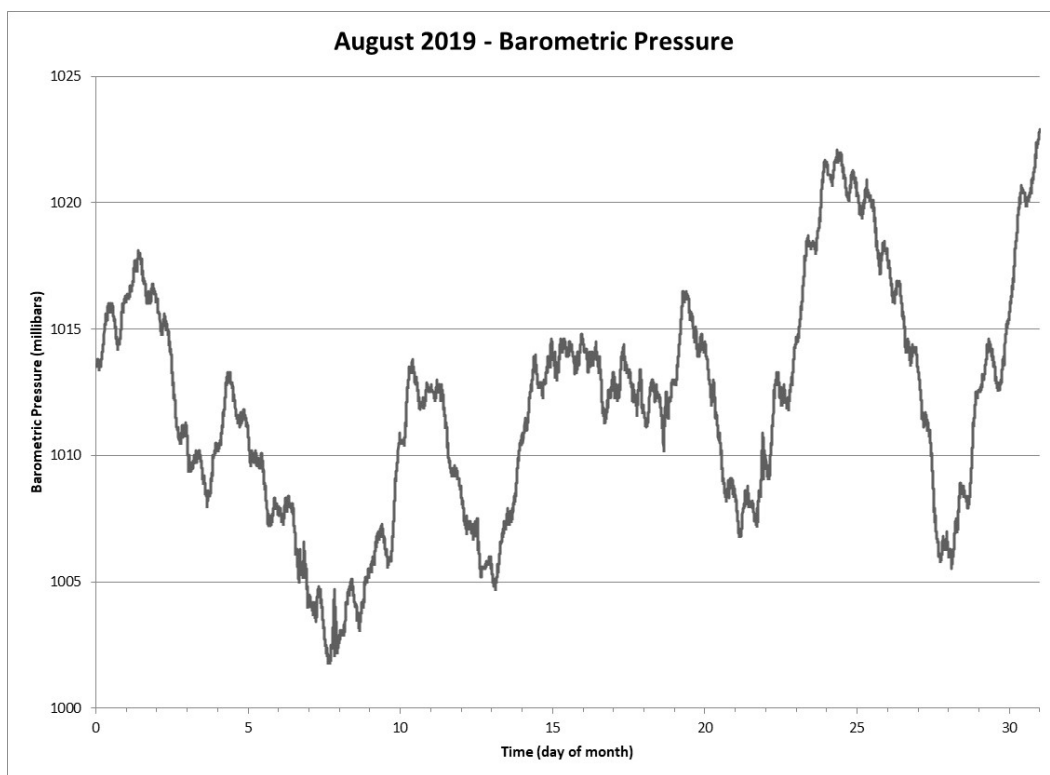


Figure 25 Barometric Pressure for the Month of August 2019

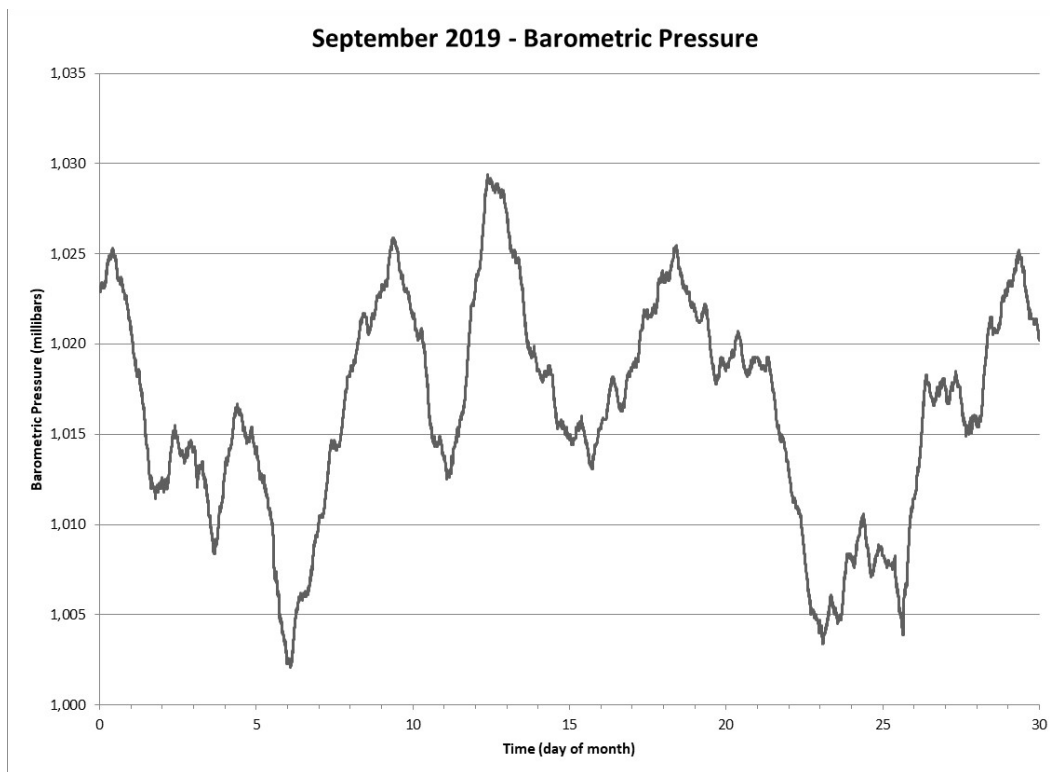


Figure 26 Barometric Pressure for the Month of September 2019

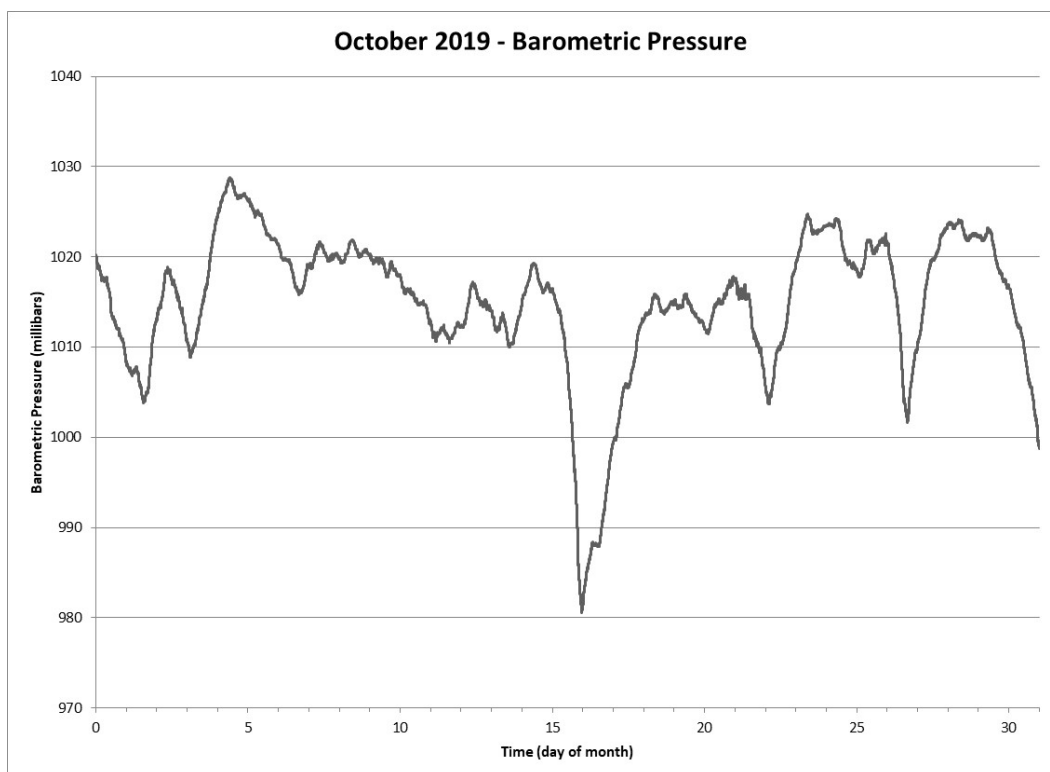


Figure 27 Barometric Pressure for the Month of October 2019

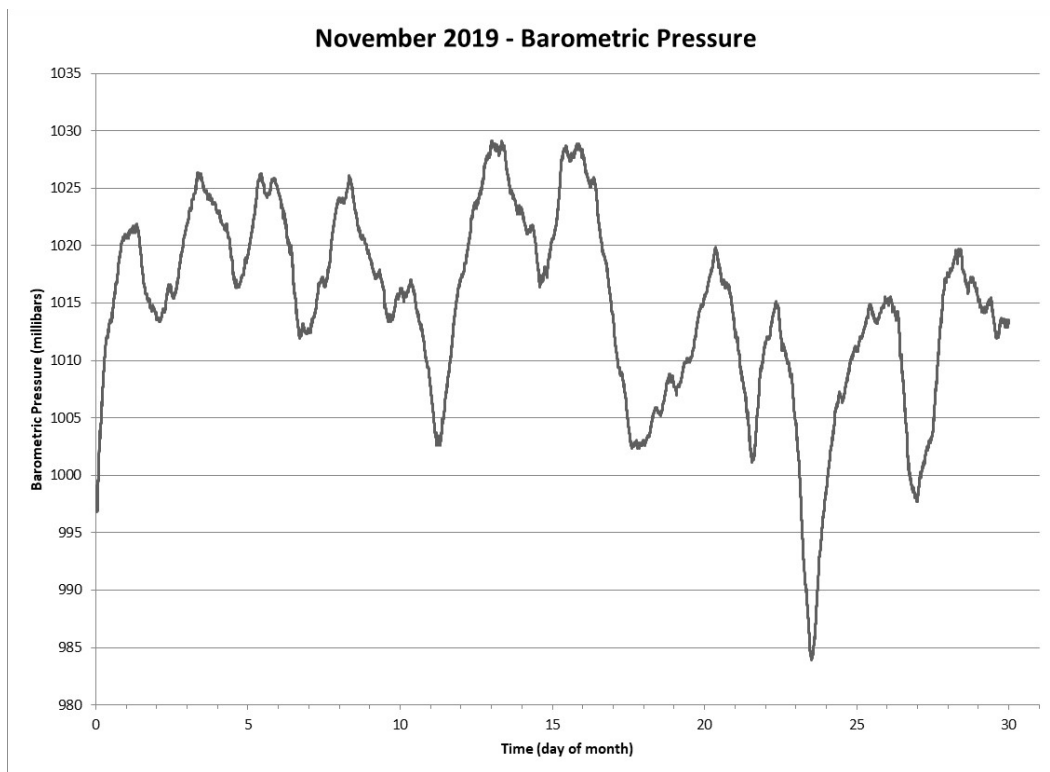


Figure 28 Barometric Pressure for the Month of November 2019

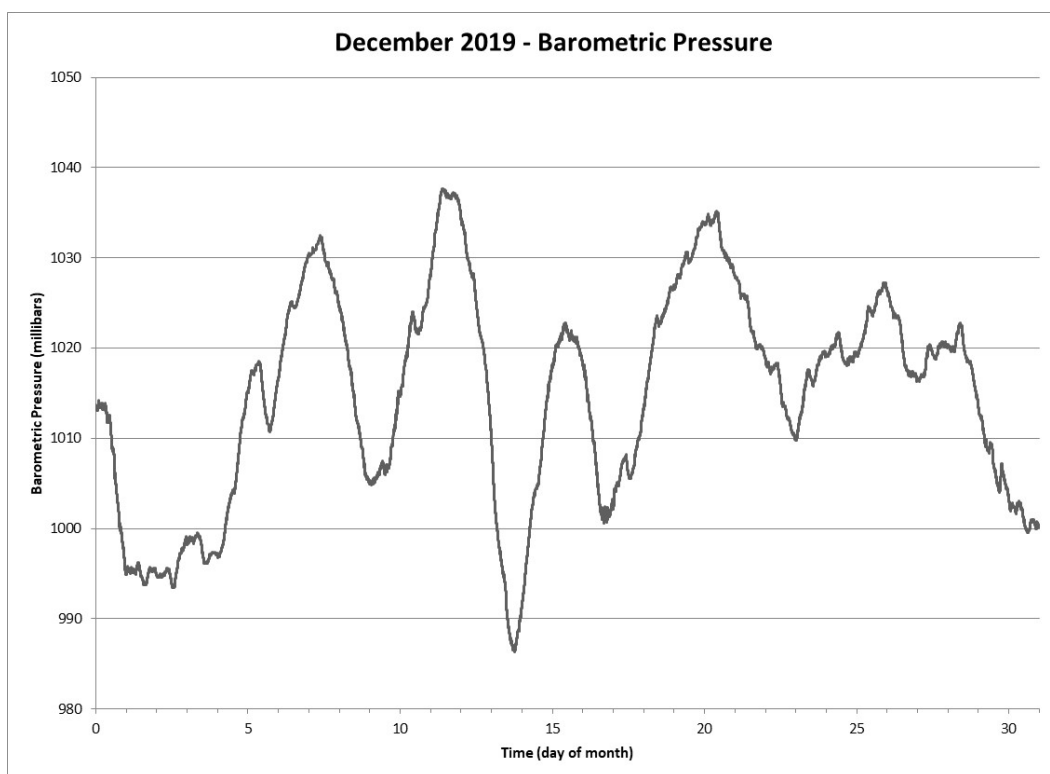


Figure 29 Barometric Pressure for the Month of December 2019

## Relative Humidity

Relative Humidity is measured at the 2-meter level. The sensors are calibrated on site and maintained to  $\pm 4\%$ . The relative humidity sensor is calibrated, in the laboratory, using saturated salt baths. The use of saturated salt baths is one of the oldest methods for generating humidity at different levels. The RH value is a function of the chemical properties of the salt when mixed with water, with different saturated salt solutions yielding different RH values. Although cumbersome, saturated salt solutions are very reliable. The saturated salt solutions are easy to make and result in a fairly constant humidity over a reasonable temperature range. BNL Met Services uses saturated aqueous salt solutions as described in ASTM E104-02 to obtain a three point calibration of the RH probes. Specific humidity calibration chamber covers that fit each probe type are used and separate chambers for each salt solution. The reference solutions are stored in sealed chambers. The specific solutions include; Sodium Chloride (NaCl) for  $75.5 \pm 0.2$  % RH @  $20^\circ\text{C}$ , Sodium Bromide (NaBr) for  $59.1 \pm 0.5$  % RH @  $20^\circ$  and Magnesium Chloride (MgCl) for  $33.1 \pm 0.2$  % RH @  $20^\circ\text{C}$ . In contrast, the Campbell (R tonic) HC2-S3 has a stated accuracy of  $\pm 0.8\%$  @  $23^\circ\text{C}$ . The ANS requirement is  $\pm 4\%$ . If the probe fails to meet the  $\pm 4\%$  it must be replaced.

The average daily humidity at BNL for 2019 was 76 %. The average daily low humidity was 51 %. The average daily high humidity was 94 %. Daily average humidity is plotted in Figure 30, daily minimum in Figure 31 and daily maximum humidity in Figure 32. Monthly data plots of the 1-minute data for relative humidity are presented in Figures 33 through 44.

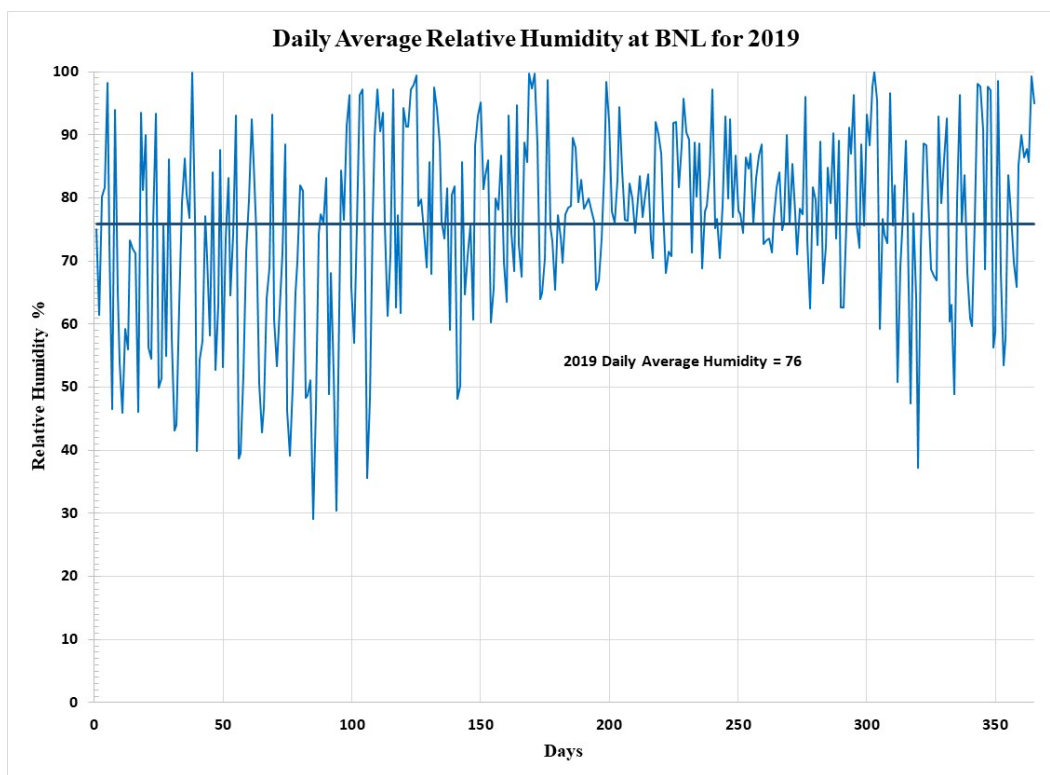


Figure 30 Daily Mean Relative Humidity at Brookhaven National Laboratory for 2019

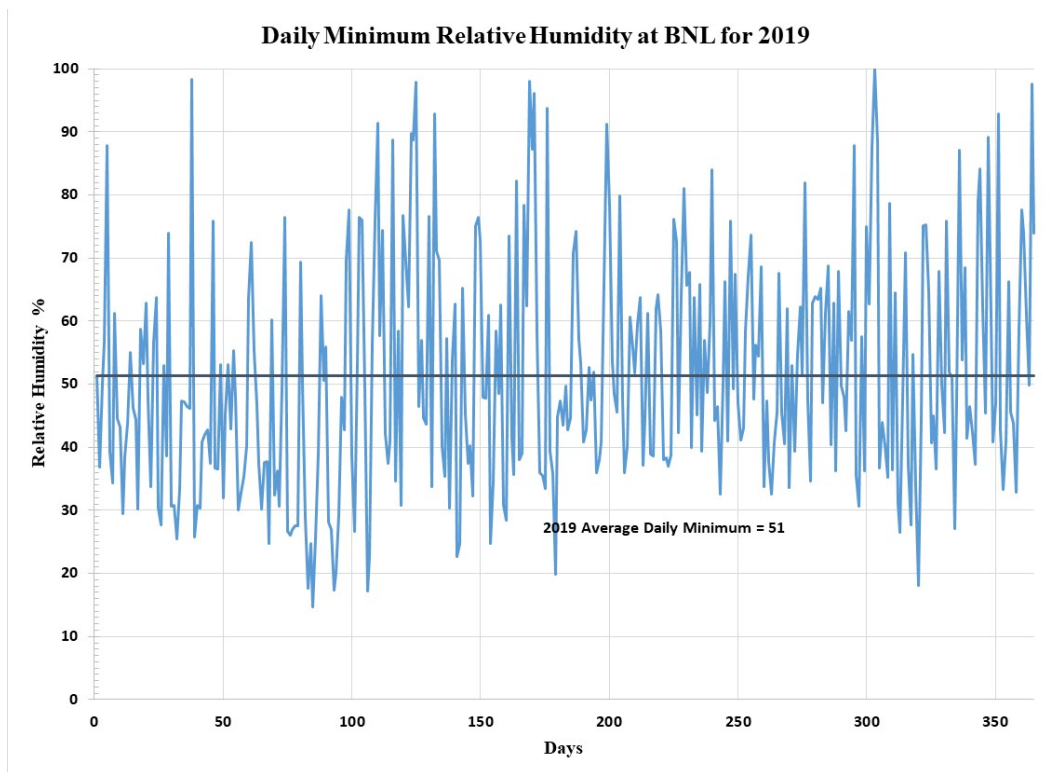


Figure 31 Minimum Daily Humidity at Brookhaven National Laboratory for 2019

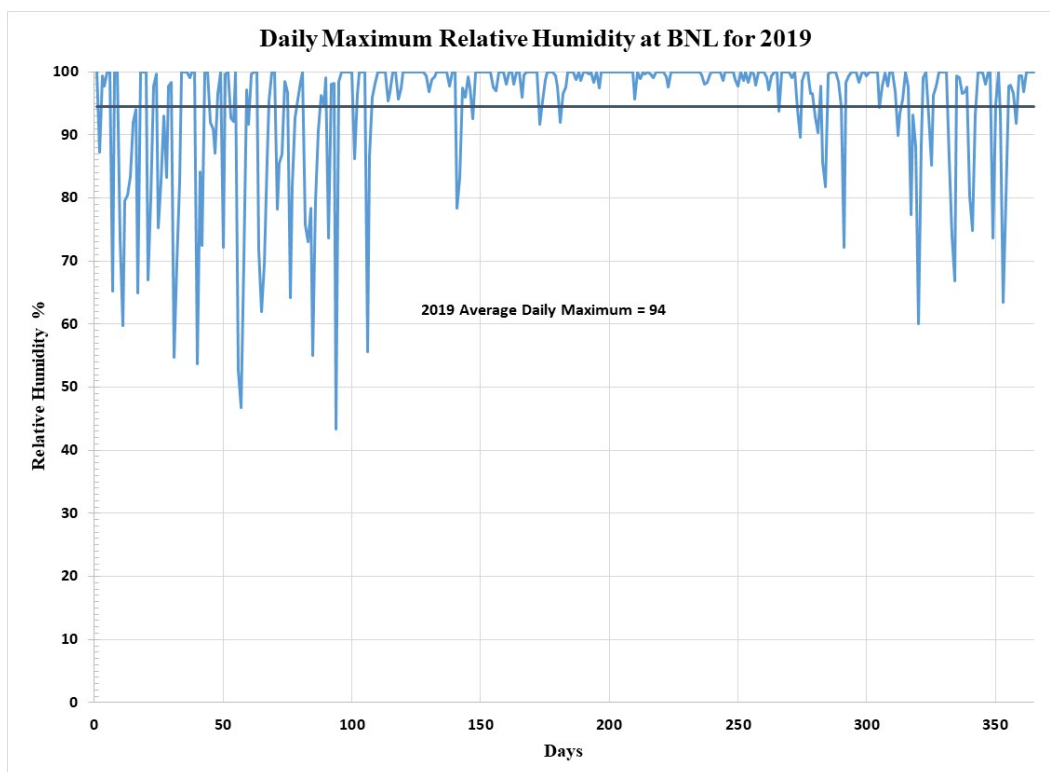


Figure 32 Maximum Daily Humidity at Brookhaven National Laboratory for 2019

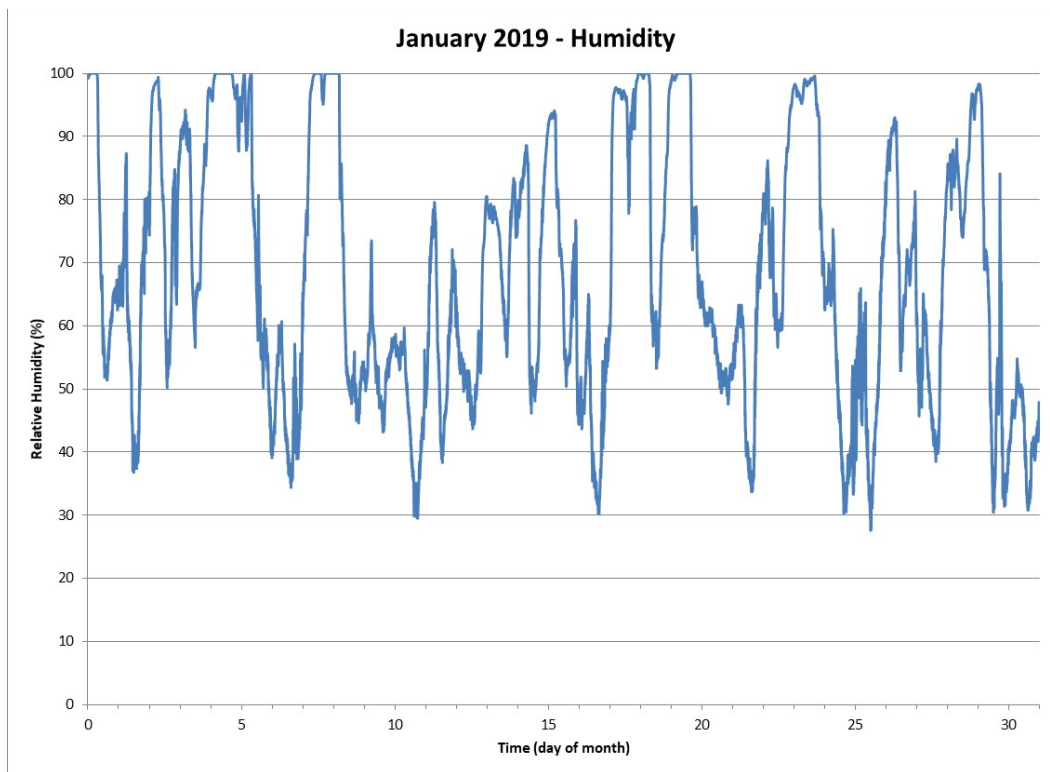


Figure 33 Relative Humidity for the Month of January 2019

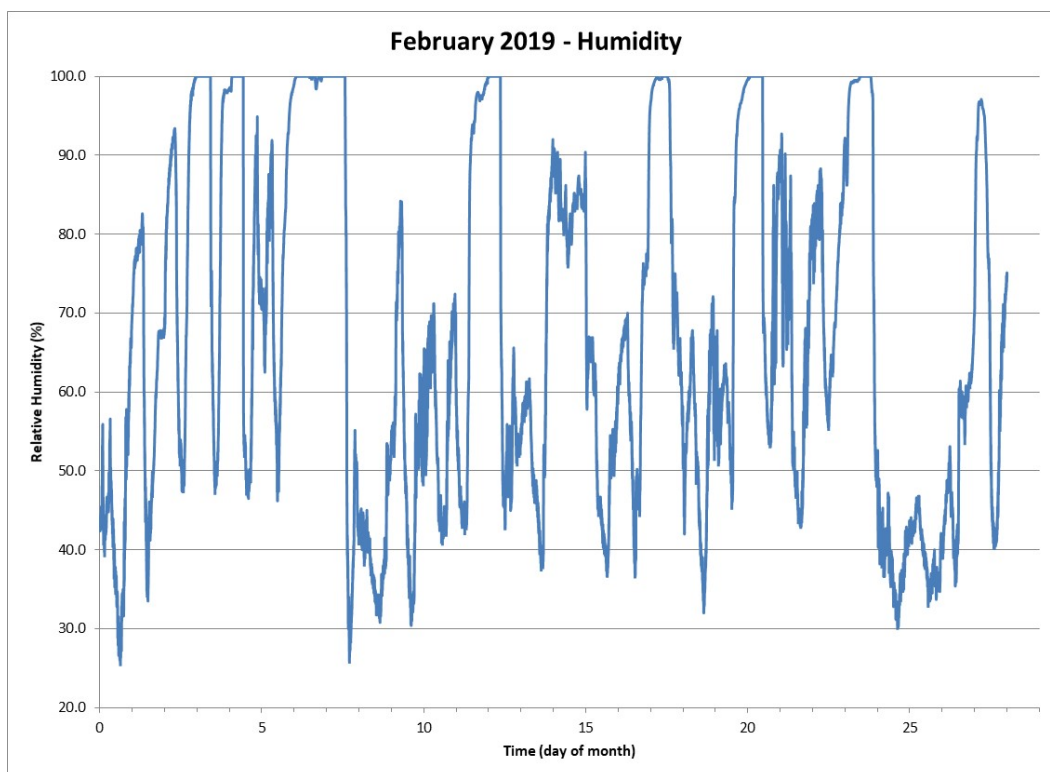


Figure 34 Relative Humidity for the Month of February 2019

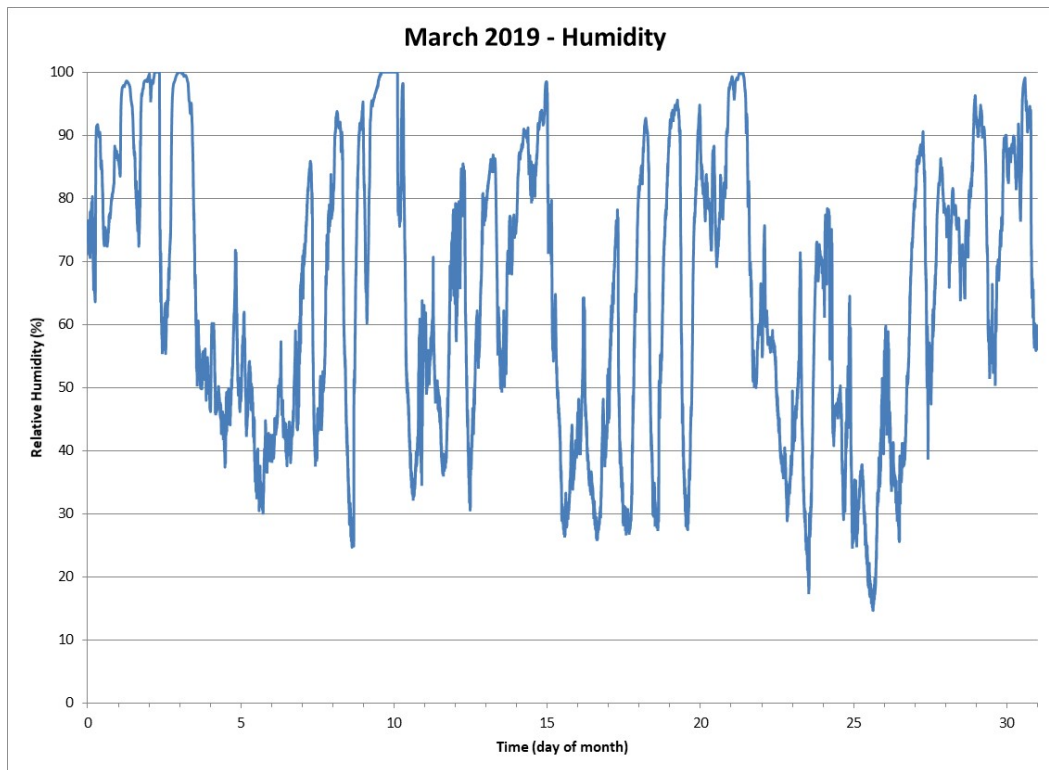


Figure 35 Relative Humidity for the Month of March 2019

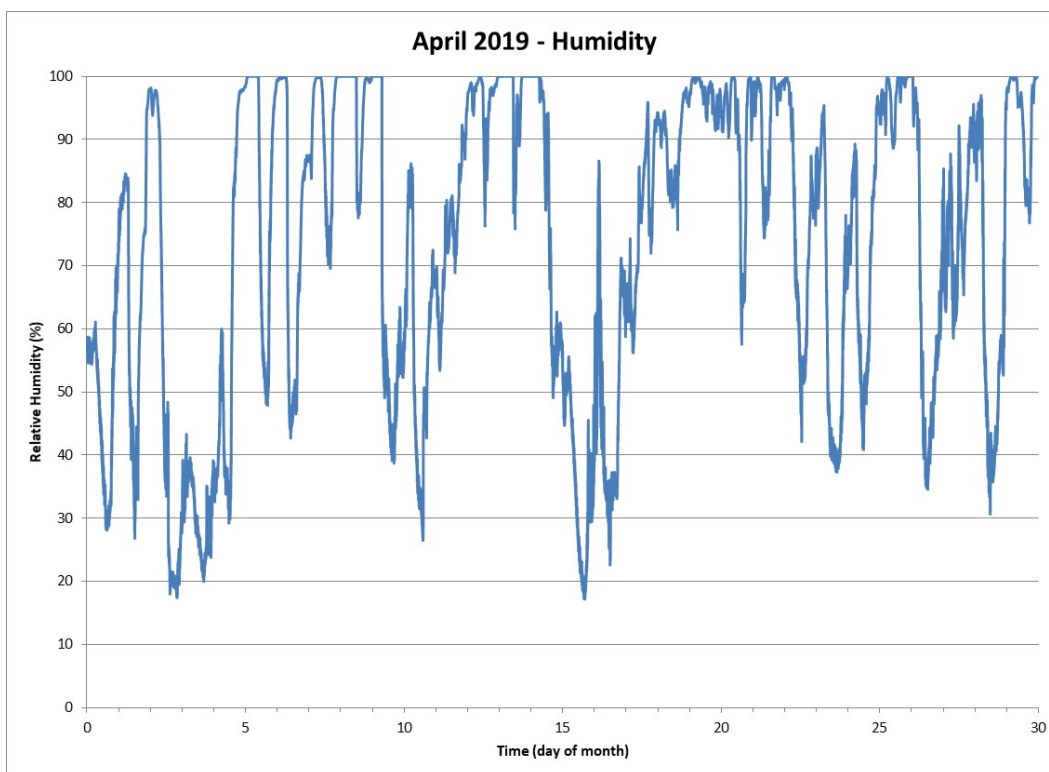


Figure 36 Relative Humidity for the Month of April 2019

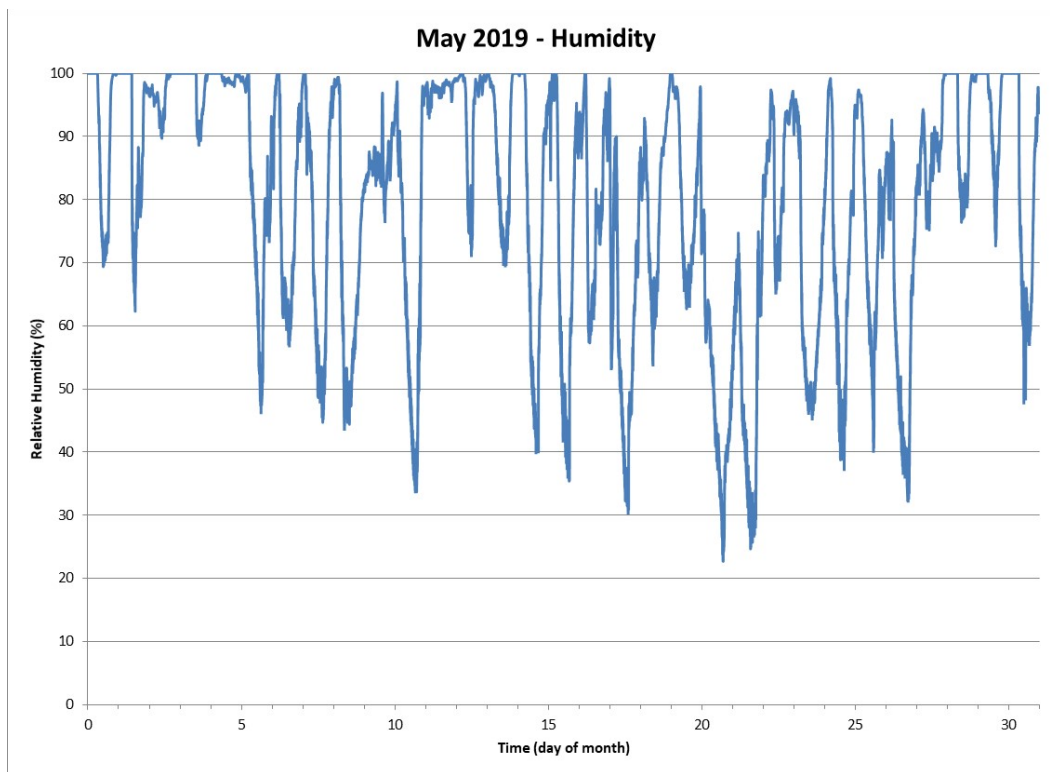


Figure 37 Relative Humidity for the Month of May 2019

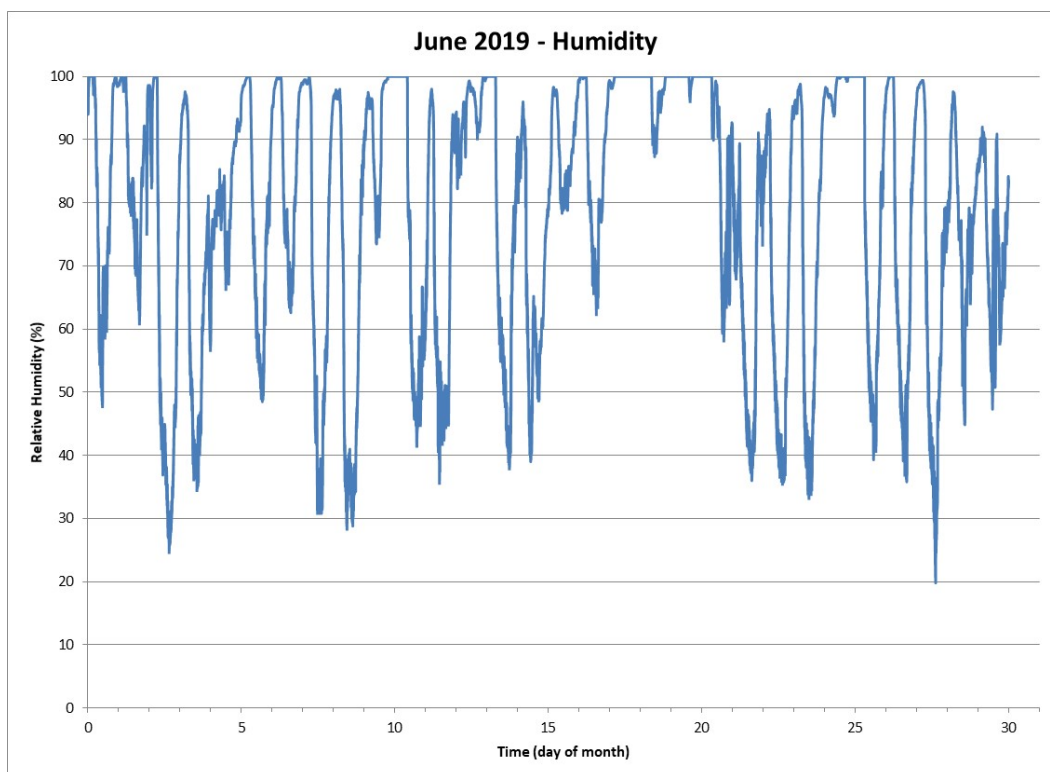


Figure 38 Relative Humidity for the Month of June 2019

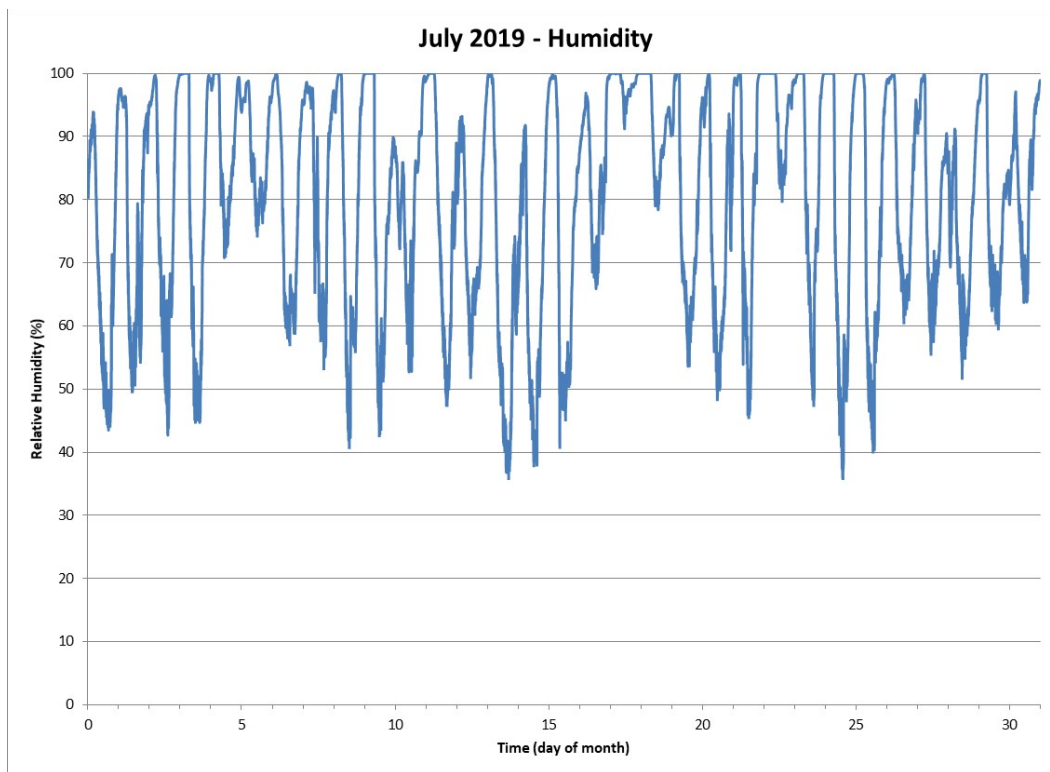


Figure 39 Relative Humidity for the Month of July 2019

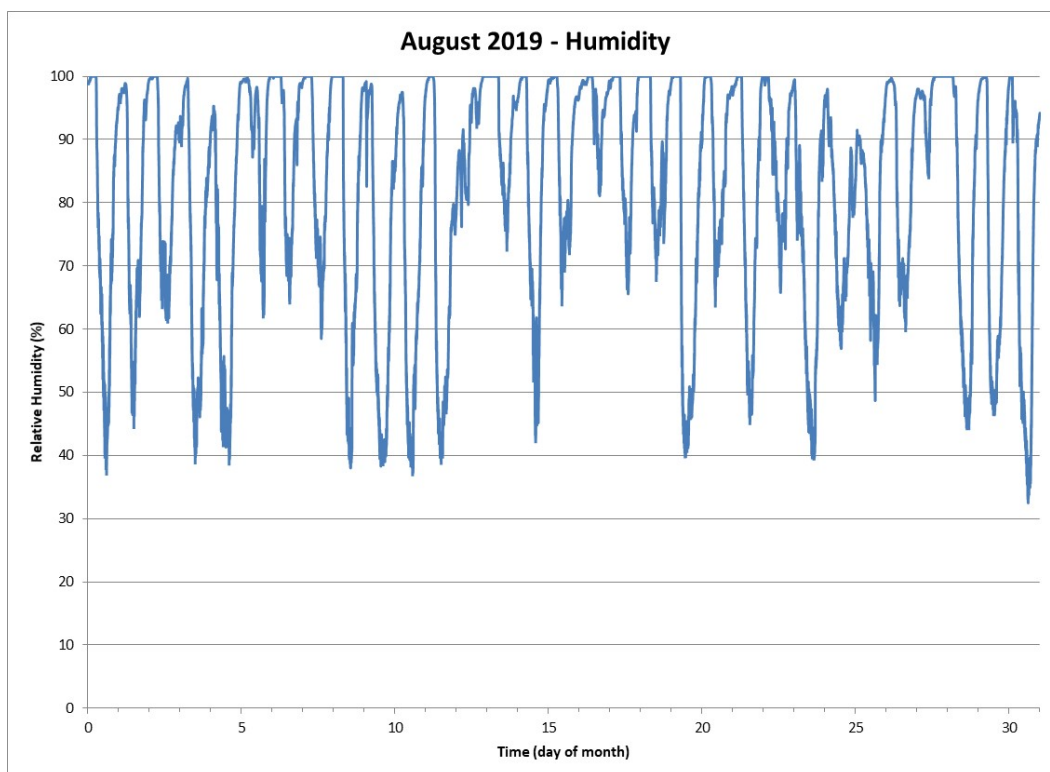


Figure 40 Relative Humidity for the Month of August 2019

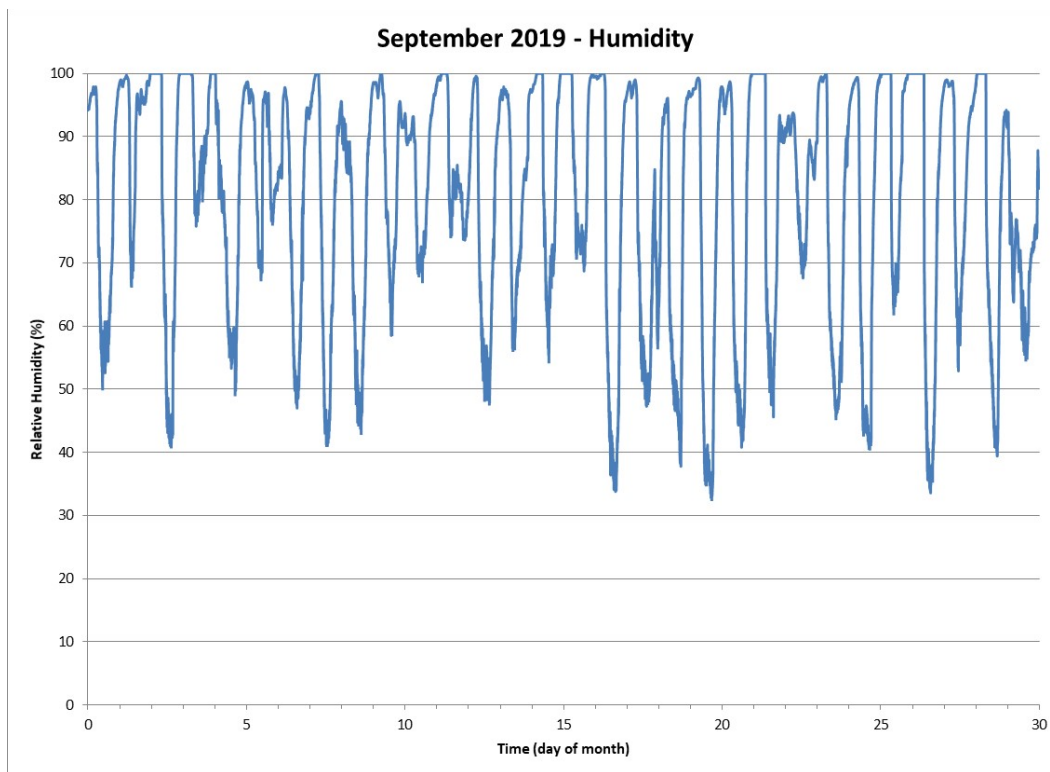


Figure 41 Relative Humidity for the Month of September 2019

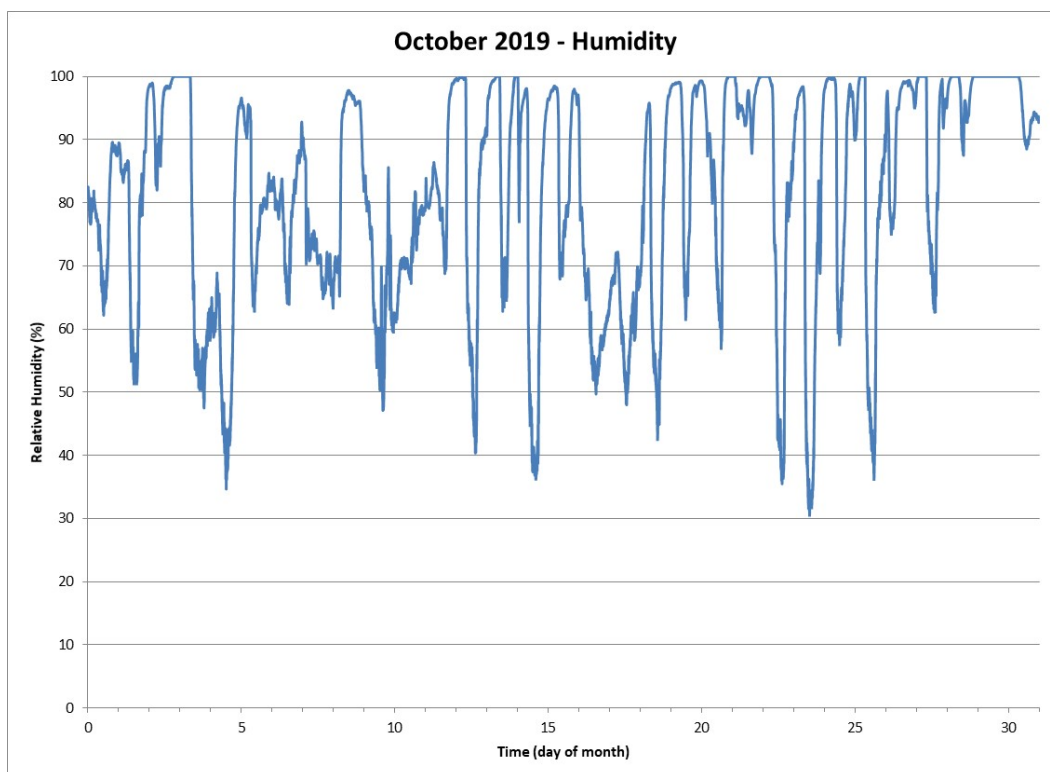


Figure 42 Relative Humidity for the Month of October 2019

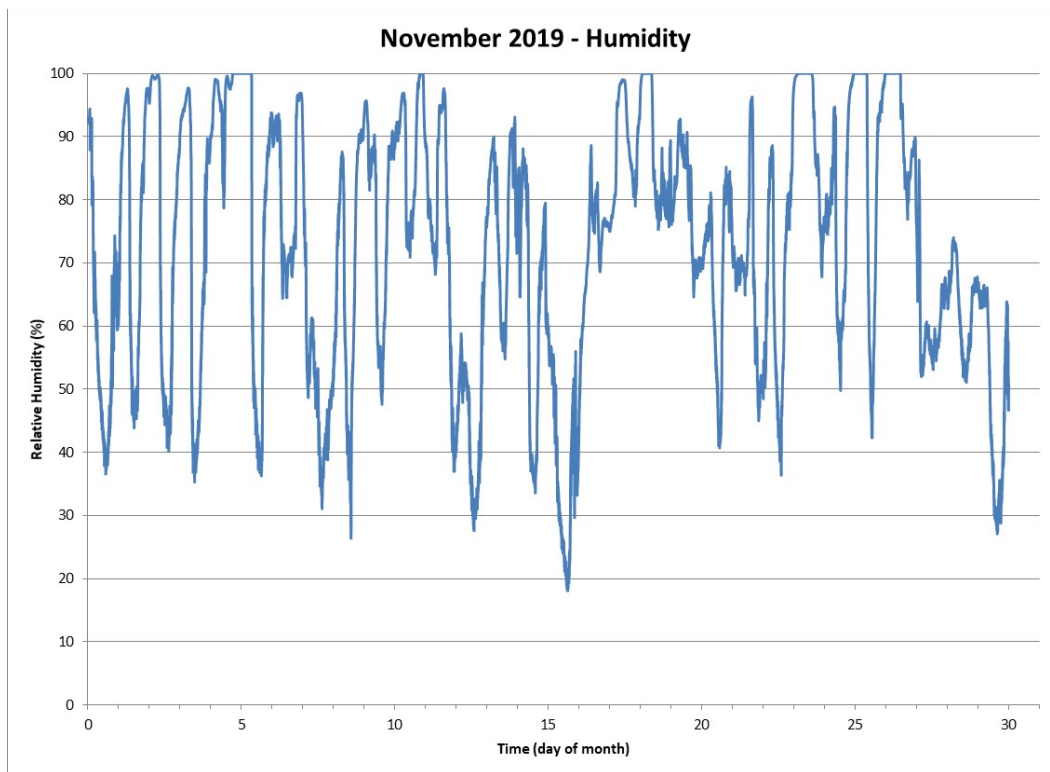


Figure 43 Relative Humidity for the Month of November 2019

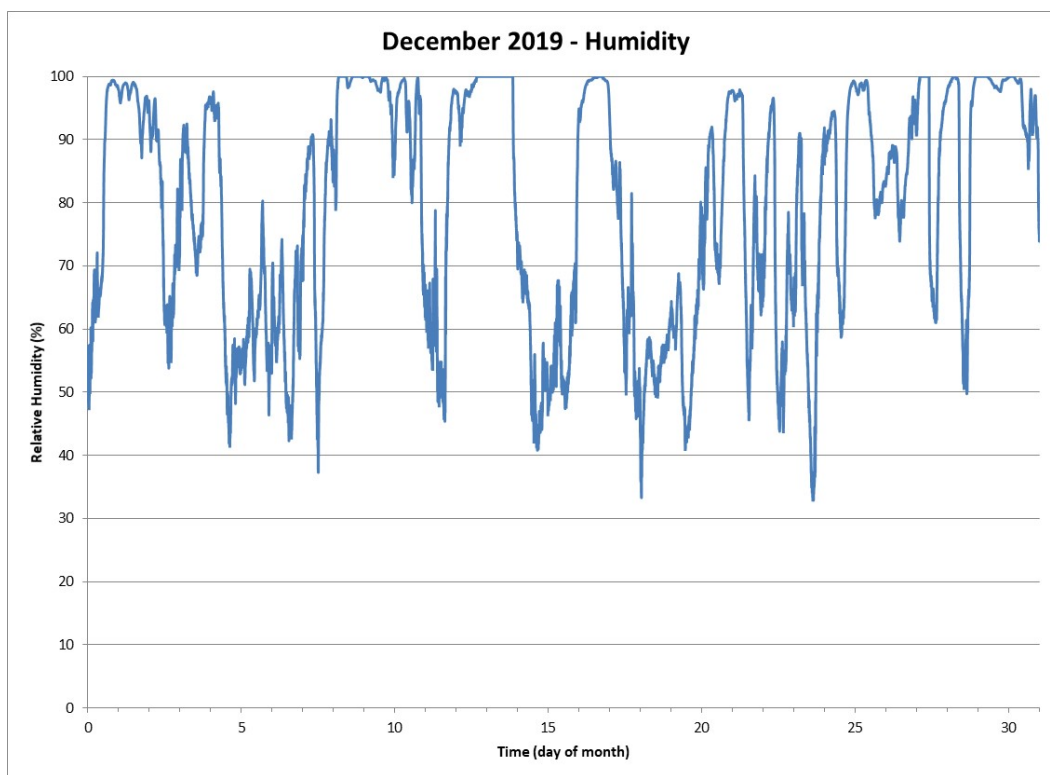


Figure 44 Relative Humidity for the Month of December 2019

## Rainfall

Rainfall is measured using a 12” NovaLynx 2500 electrically heated (for snowfall events), tipping bucket rain gauges which are calibrated annually. The gauges measure tips for each 0.01” of rain. Calibration is accomplished by BNL personnel using the NovaLynx Calibration Assembly (model 260-2595) and is completed in-situ. Accuracy is  $\pm 1\%$  for 1 to 3 inches per hour rainfall and  $\pm 3\%$  for 0 to 6 inches per hour. If the test results are outside this accuracy requirement the tipping bucket is adjusted to bring it within specs. Total rainfall for the year was 52.10”. Daily rainfall totals for the year are depicted in Figure 45. Historic rainfall totals are given in Figure 46. Monthly data charts of daily rainfall totals are presented in Figures 47 through 58. Table 7 lists the historic monthly rainfall totals along with monthly averages, maximums and minimums from 1949 to present.

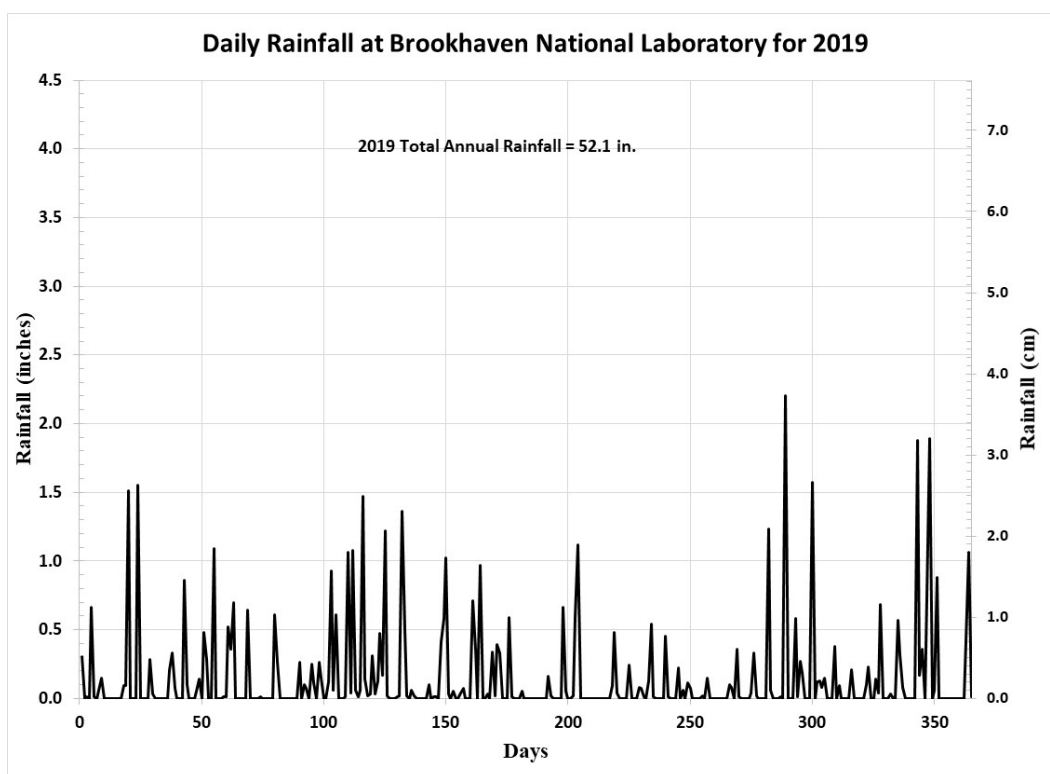


Figure 45 Daily Rainfall Totals at Brookhaven National Laboratory for 2019

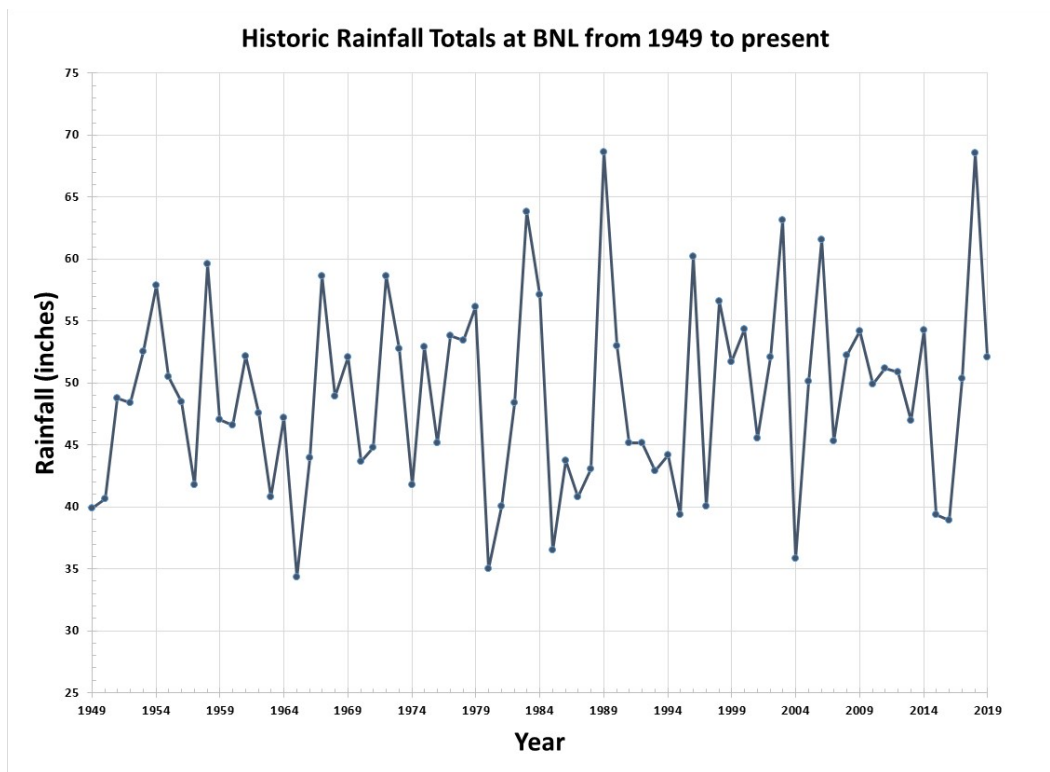


Figure 46 Historic Rainfall Totals occurring at Brookhaven National Laboratory from 1949 to present

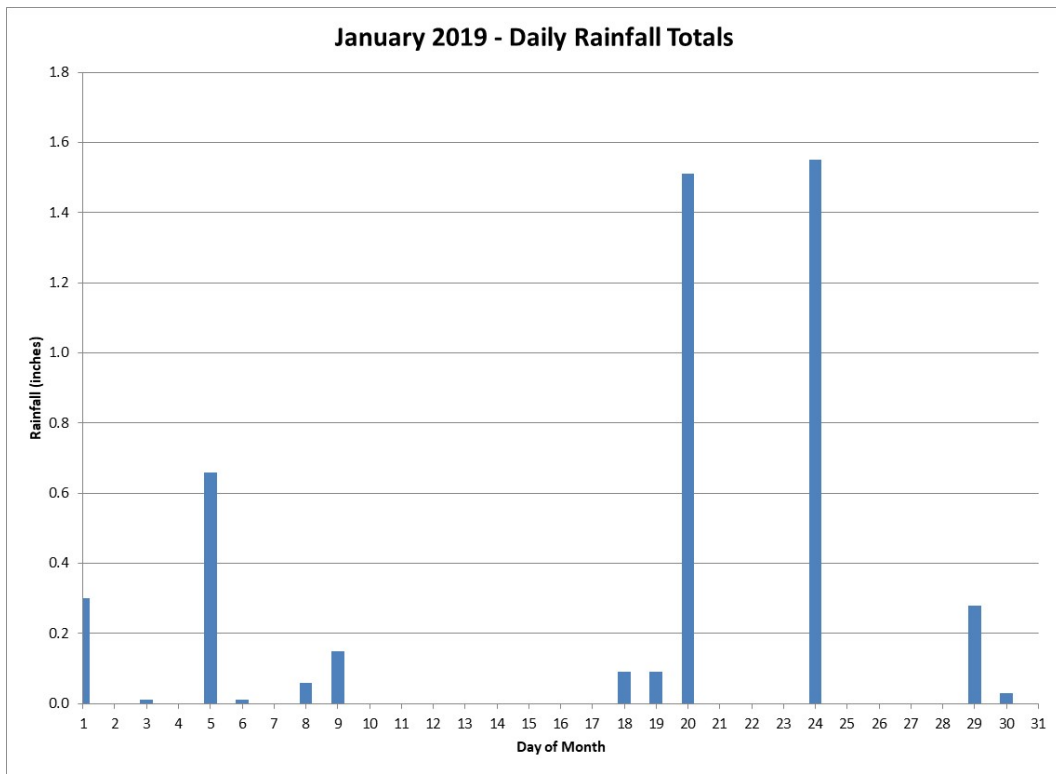


Figure 47 Daily Rainfall for the Month of January 2019

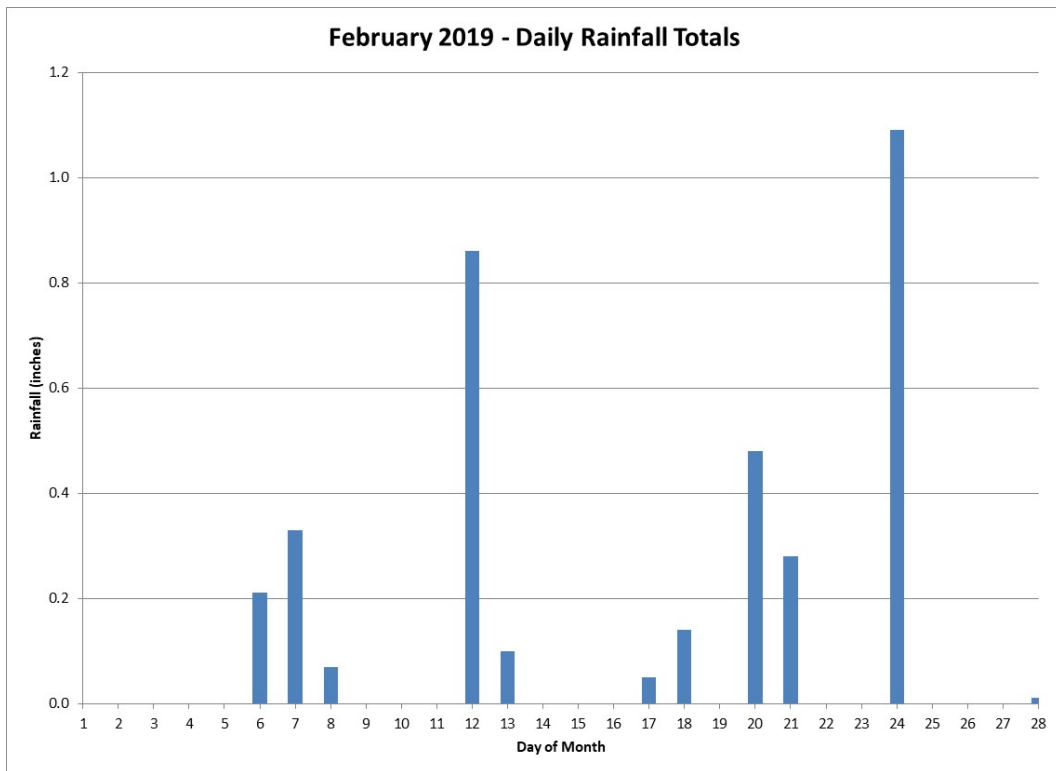


Figure 48 Daily Rainfall for the Month of February 2019

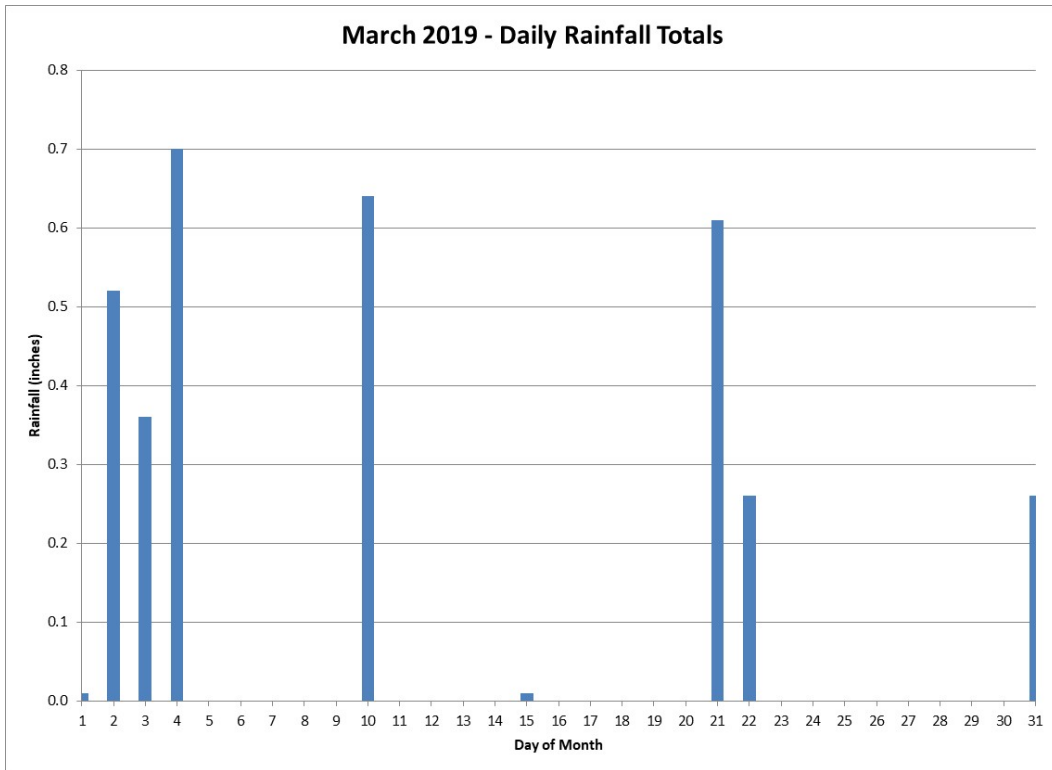


Figure 49 Daily Rainfall for the Month of March 2019

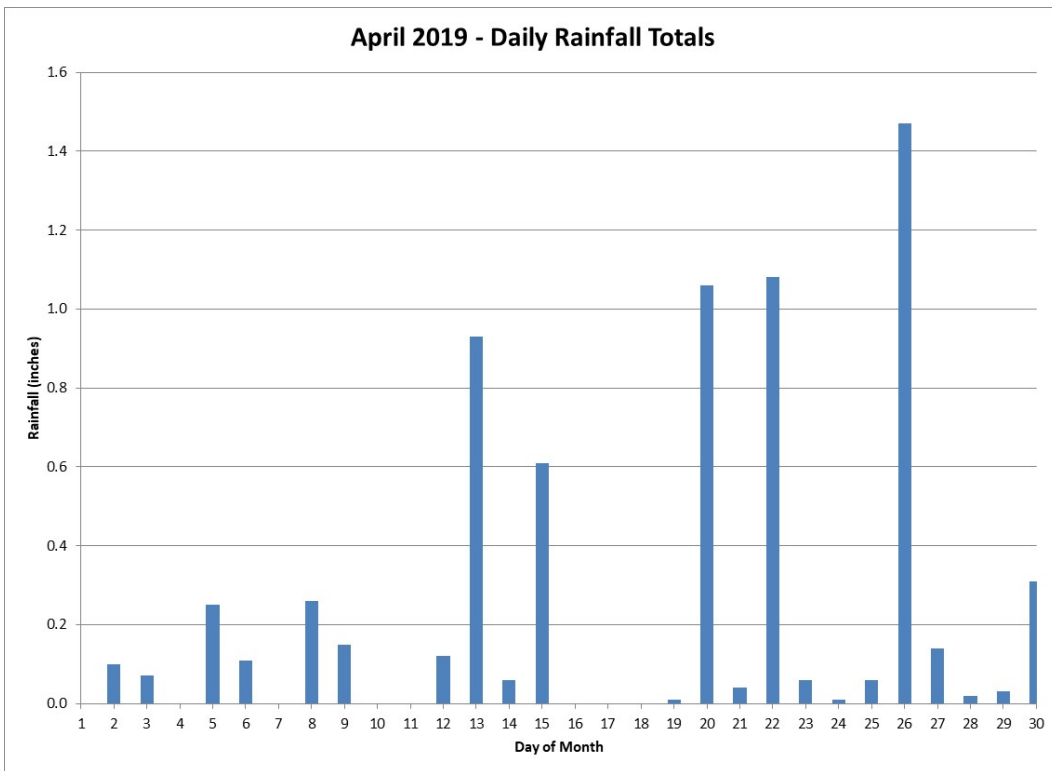


Figure 50 Daily Rainfall for the Month of April 2019

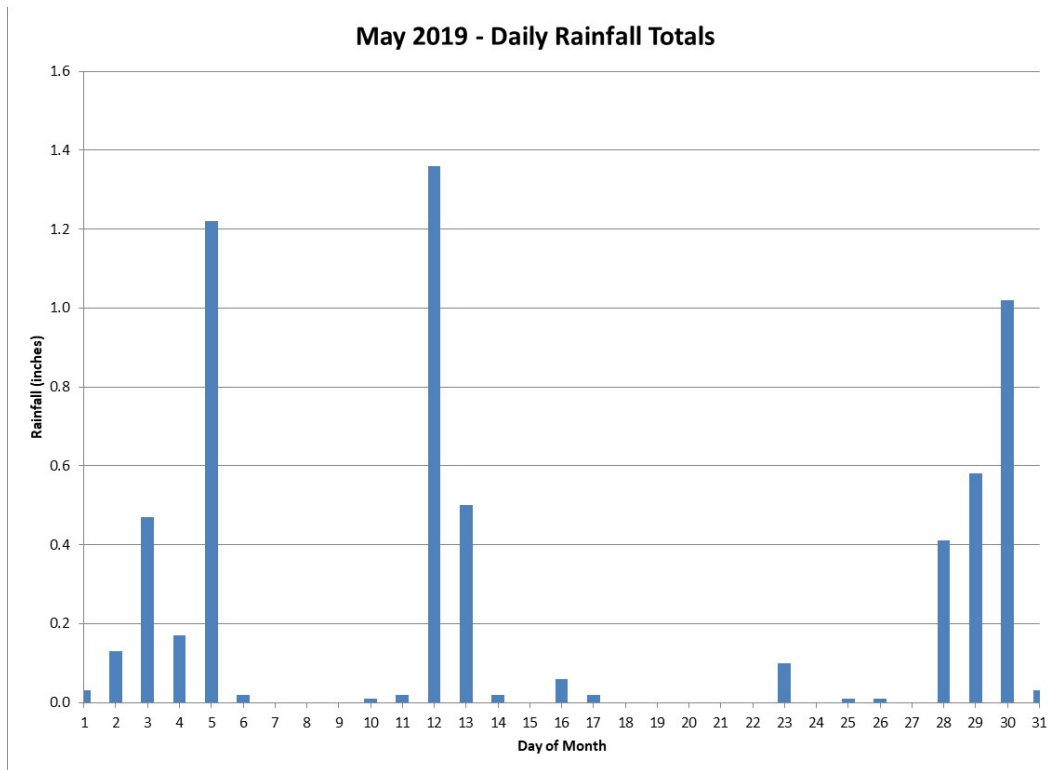


Figure 51 Daily Rainfall for the Month of May 2019

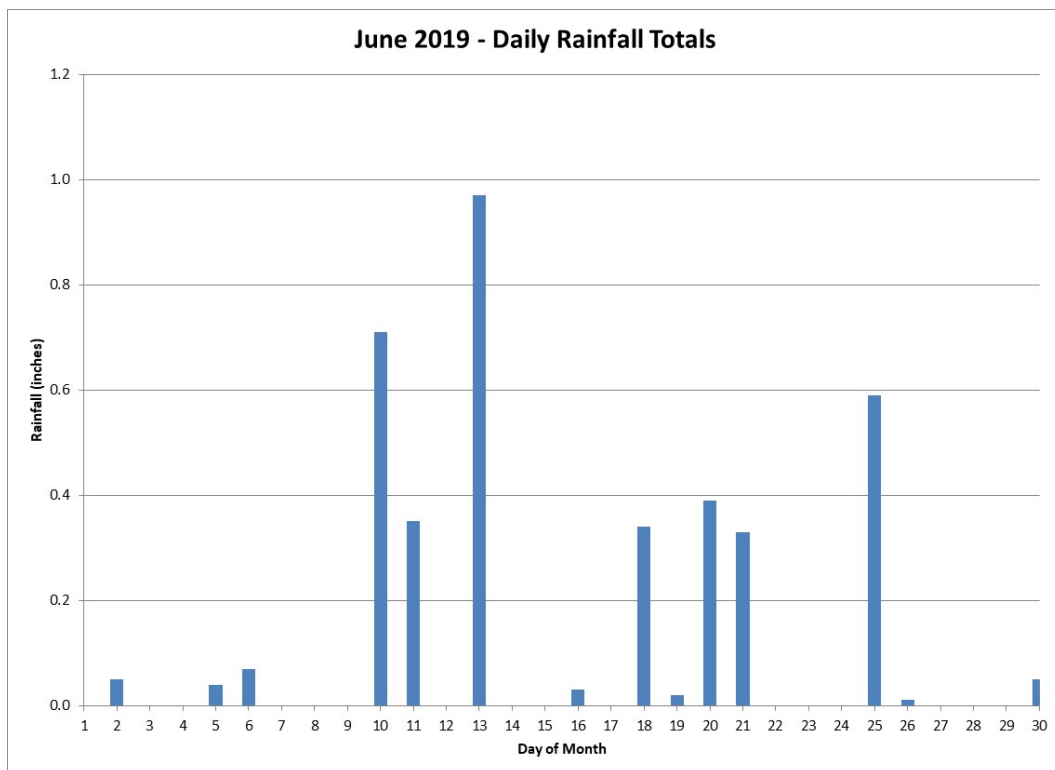


Figure 52 Daily Rainfall for the Month of June 2019

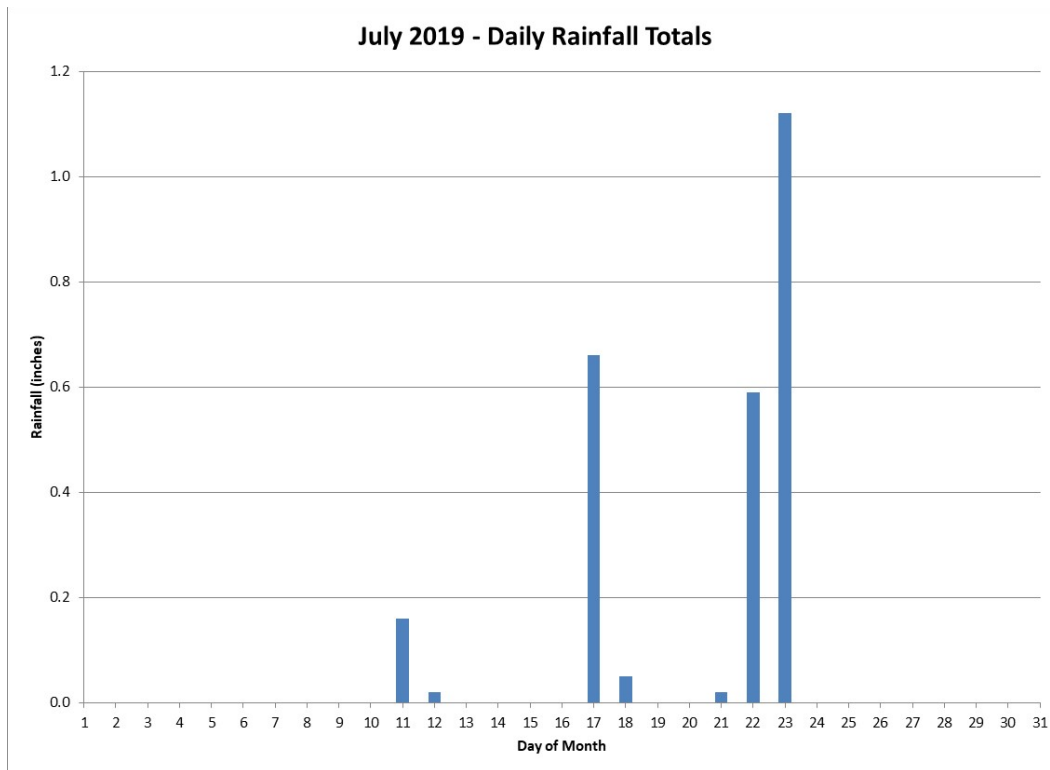


Figure 53 Daily Rainfall for the Month of July 2019

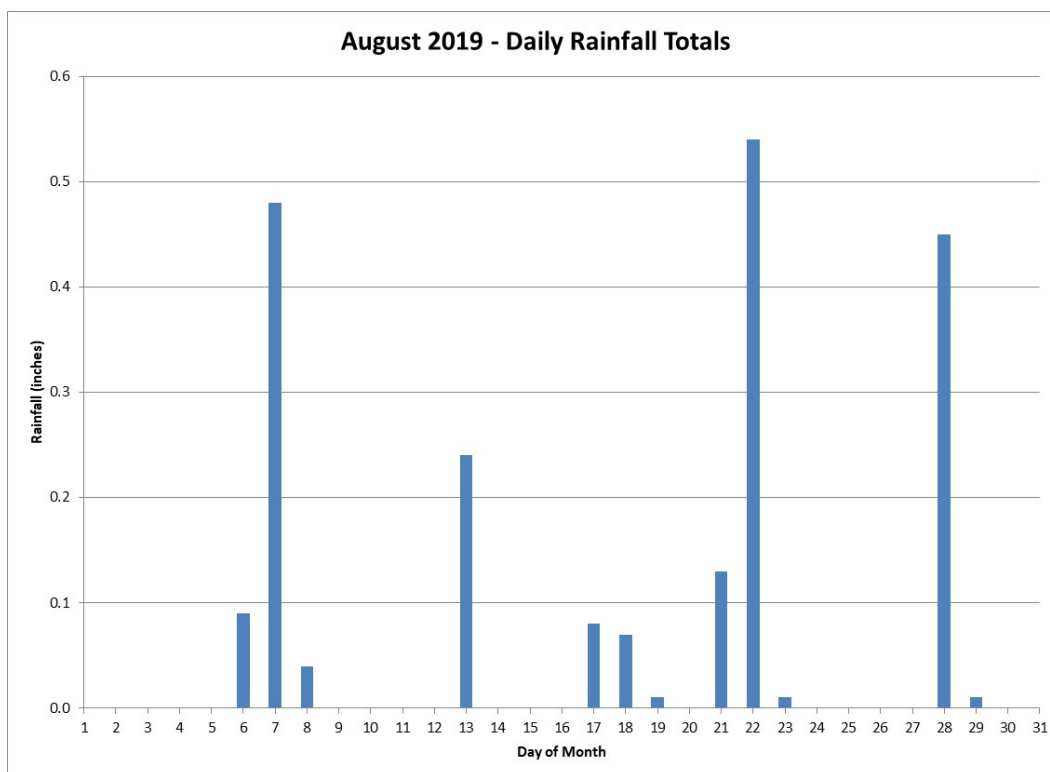


Figure 54 Daily Rainfall for the Month of August 2019

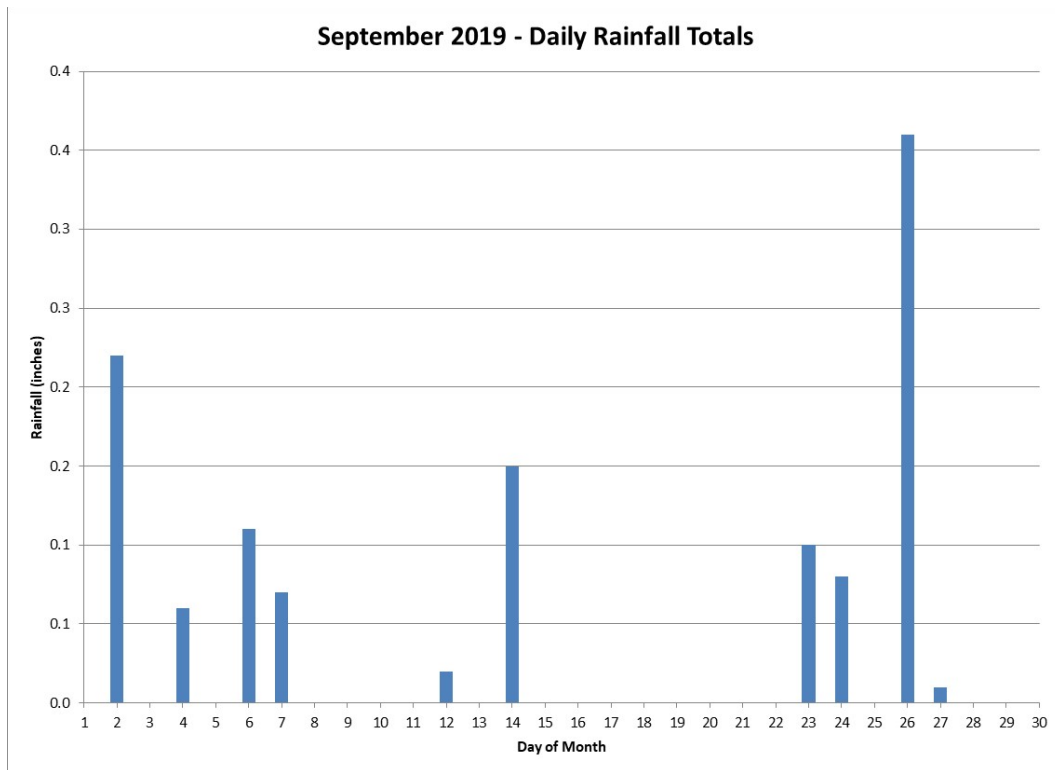


Figure 55 Daily Rainfall for the Month of September 2019

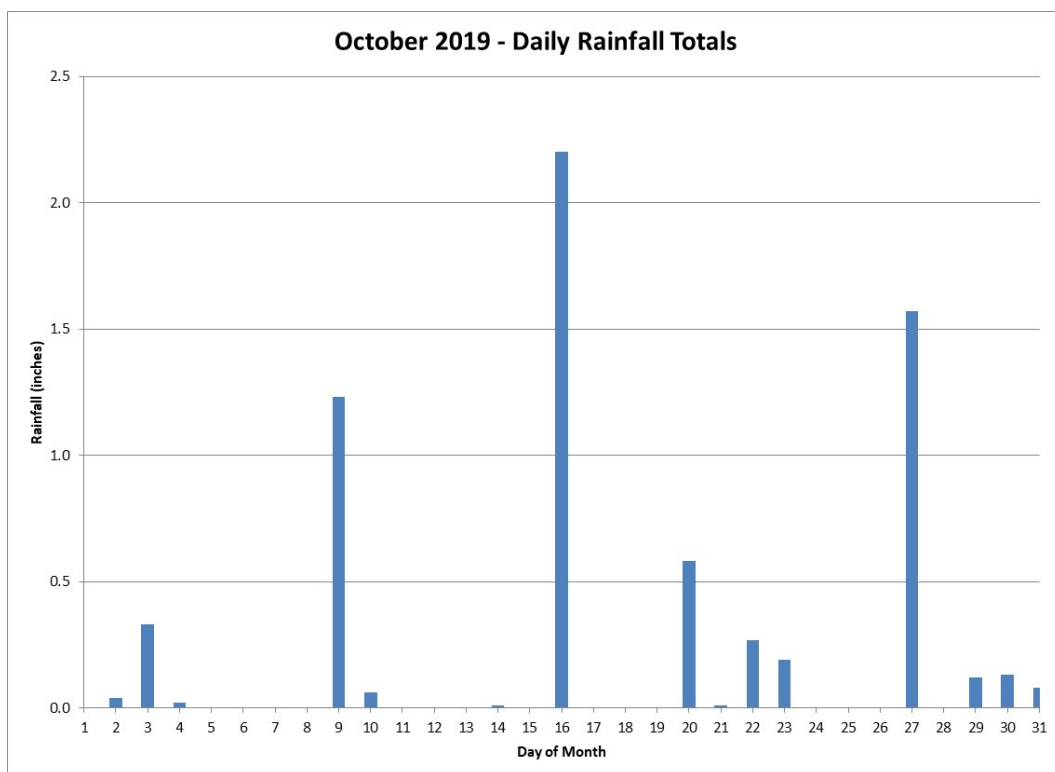


Figure 56 Daily Rainfall for the Month of October 2019

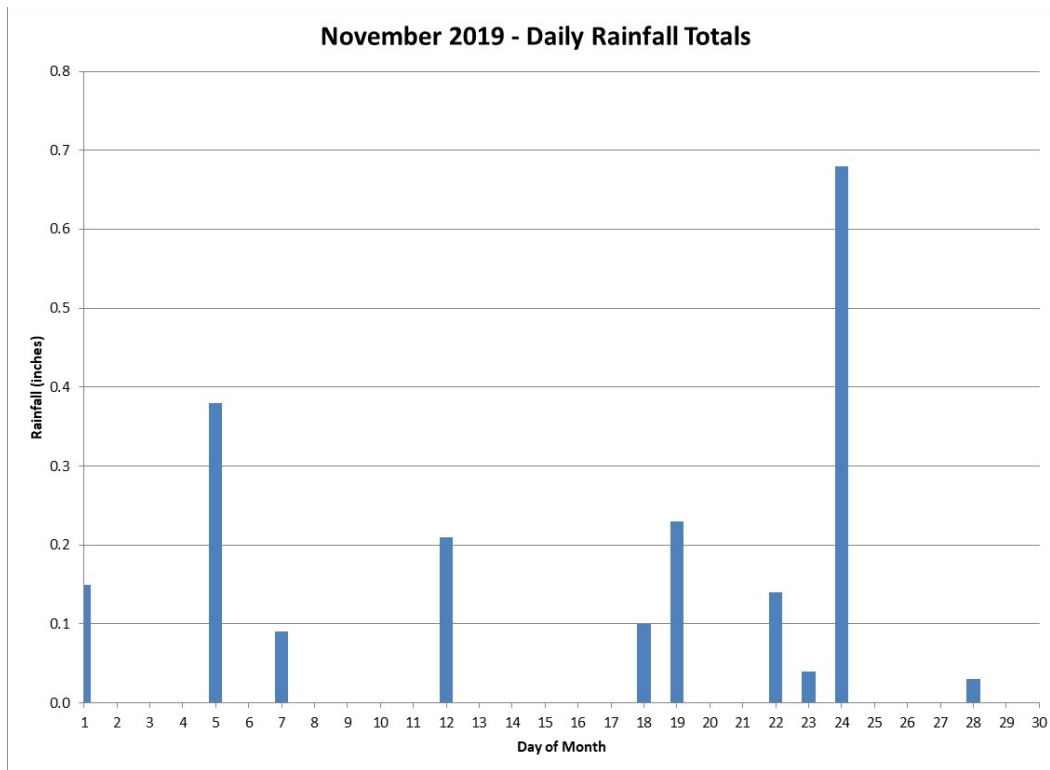


Figure 57 Daily Rainfall for the Month of November 2019

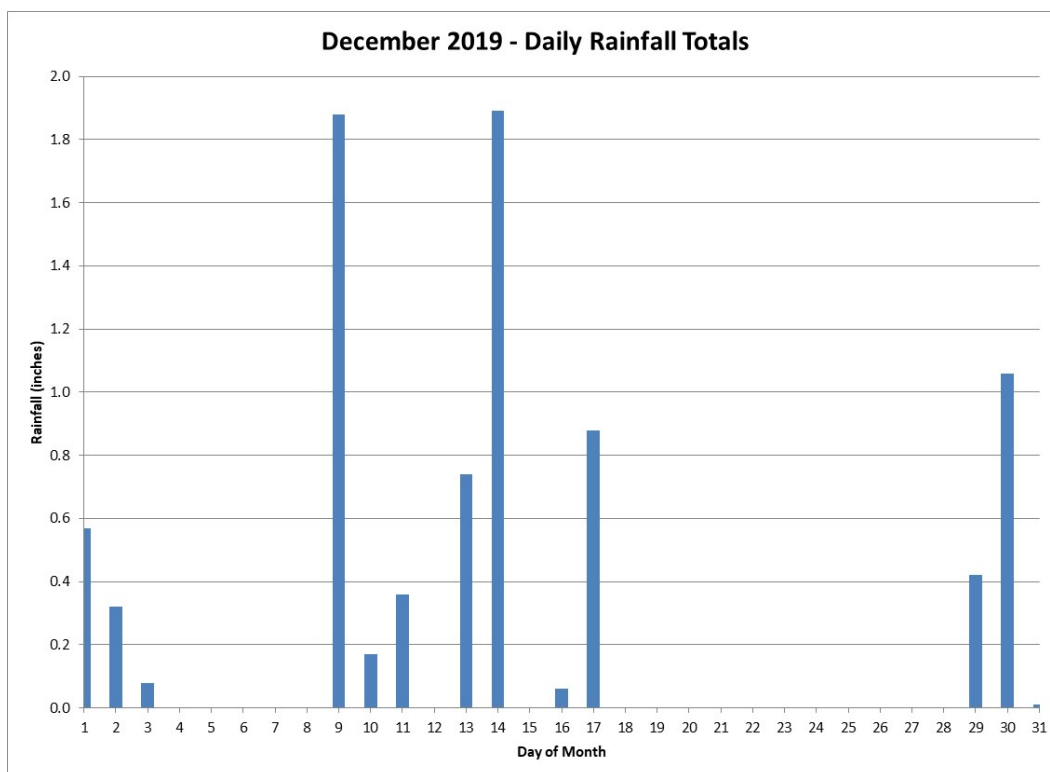


Figure 58 Daily Rainfall for the Month of December 2019

**Table 7. Historic Monthly Precipitation for Brookhaven National Laboratory from 1949 to present (@ 2 meters)**

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1949	5.55	4.71	2.88	3.63	3.32	Trace	3.07	5.21	3.49	1.74	2.96	3.36	39.92
1950	2.80	4.28	3.98	2.41	5.23	2.72	3.22	4.26	1.38	1.69	4.34	4.36	40.67
1951	3.75	4.99	5.02	3.42	3.68	2.64	2.08	4.50	1.06	5.48	6.01	6.17	48.80
1952	7.10	3.54	5.44	3.61	7.64	2.78	1.00	7.61	1.35	0.31	3.56	4.45	48.39
1953	6.73	4.16	10.36	5.59	3.34	1.66	2.76	2.40	0.90	3.17	5.03	6.43	52.53
1954	2.74	2.18	4.21	5.36	4.08	1.69	0.94	<b>11.98</b>	<b>10.47</b>	2.44	5.42	6.39	57.90
1955	<b>0.62</b>	3.26	4.79	4.28	0.95	2.53	1.65	9.04	3.96	11.43	7.19	<b>0.82</b>	50.52
1956	3.52	6.32	5.47	2.97	2.63	3.00	5.79	1.50	3.64	2.95	4.63	6.03	48.45
1957	2.36	2.53	3.20	4.44	1.46	<b>0.42</b>	2.84	4.25	3.57	3.86	4.41	8.45	41.79
1958	7.96	4.58	6.65	6.34	5.81	2.28	3.42	5.37	4.24	7.39	2.88	2.68	59.60
1959	2.60	2.06	6.71	3.93	1.75	5.35	6.85	3.72	1.36	3.13	4.46	5.12	47.04
1960	3.59	5.48	3.38	3.27	2.54	2.13	6.03	1.79	7.49	3.94	2.62	4.31	46.57
1961	3.56	4.10	4.60	5.70	6.17	2.30	5.61	4.23	6.23	3.06	2.89	3.70	52.15
1962	4.38	5.77	3.63	3.31	1.12	3.55	1.64	7.64	4.07	4.62	5.04	2.83	47.60
1963	3.27	3.88	4.27	2.56	3.08	5.51	2.65	2.10	3.66	<b>0.18</b>	6.89	2.78	40.83
1964	5.89	4.76	3.56	8.37	<b>0.63</b>	1.41	4.40	1.16	3.02	4.29	3.07	6.63	47.19
1965	4.88	3.03	2.74	4.20	1.63	1.69	3.43	5.15	1.51	2.15	1.83	2.11	<b>34.35</b>
1966	4.57	5.18	1.73	2.13	6.55	1.40	1.12	3.23	6.53	4.45	2.89	4.15	43.93
1967	1.65	3.98	8.18	4.14	7.98	5.30	6.01	5.43	2.24	2.11	4.00	7.60	58.62
1968	3.00	2.21	7.54	2.00	4.95	4.24	<b>0.50</b>	3.10	2.08	3.01	8.09	8.22	48.94
1969	1.04	4.03	3.62	5.15	2.44	2.06	<b>8.62</b>	5.51	3.60	3.69	4.48	7.83	52.07
1970	0.81	4.37	5.44	4.57	3.44	1.77	3.10	6.08	2.42	1.41	6.52	3.73	43.66
1971	2.95	<b>6.45</b>	3.55	3.30	3.80	0.92	5.03	3.86	2.12	3.41	6.86	2.57	44.82
1972	2.41	6.12	5.40	4.53	6.10	7.30	1.03	1.29	3.08	7.64	7.51	6.22	58.63
1973	4.44	4.36	4.38	7.77	5.46	3.25	4.45	3.11	2.51	2.79	2.22	8.00	52.74
1974	4.96	2.82	5.06	3.49	3.13	2.50	0.81	2.55	5.10	2.66	1.94	6.78	41.80
1975	6.50	4.06	4.27	3.89	3.45	5.37	3.33	2.01	5.58	3.61	5.89	4.92	52.88
1976	5.98	3.57	3.30	2.27	3.89	3.27	4.32	7.57	2.07	5.42	<b>0.54</b>	2.96	45.16

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1977	3.09	2.46	5.47	4.28	2.04	4.31	1.51	5.49	5.73	6.12	6.39	6.93	53.82
1978	10.72	2.60	3.33	2.39	6.47	0.81	4.63	5.22	4.26	4.11	2.79	6.12	53.45
1979	13.01	5.27	3.53	4.96	4.09	2.15	0.61	7.76	3.20	4.57	3.95	3.02	56.12
1980	2.02	1.18	7.20	6.16	1.52	3.60	1.92	1.56	0.98	3.59	4.20	1.06	34.99
1981	1.15	5.16	1.80	4.59	2.17	3.14	2.69	0.96	5.17	4.49	3.16	5.55	40.03
1982	7.20	2.90	3.38	5.44	1.71	12.85	1.77	3.45	1.40	2.07	3.87	2.38	48.42
1983	4.07	4.36	8.68	11.09	4.22	2.63	4.20	4.48	2.09	3.67	8.68	5.67	63.84
1984	2.87	6.38	6.92	5.41	8.08	6.68	7.06	1.02	4.16	3.20	2.40	2.98	57.16
1985	1.07	1.82	2.62	1.56	4.87	6.38	2.30	4.89	1.54	1.53	6.85	1.10	36.53
1986	3.96	3.46	3.17	2.35	1.09	1.66	5.02	5.69	0.86	2.25	6.72	7.50	43.73
1987	6.74	1.21	5.95	4.32	1.83	1.86	1.48	4.38	4.05	2.22	3.55	3.20	40.79
1988	3.59	4.81	4.22	2.17	2.58	1.43	3.93	1.36	3.52	3.87	9.05	2.52	43.05
1989	2.23	4.09	5.20	4.66	10.47	7.24	5.84	9.17	4.45	8.90	5.16	1.25	68.66
1990	5.24	2.92	2.14	4.96	6.52	3.95	2.64	6.75	3.04	7.17	1.78	5.90	53.01
1991	4.41	1.86	5.45	4.30	2.78	1.87	2.11	9.19	4.45	2.61	1.80	4.30	45.13
1992	2.40	2.18	3.34	1.78	3.05	4.90	4.76	5.61	3.51	1.07	5.96	6.60	45.16
1993	2.47	4.10	7.11	3.81	1.71	1.37	1.84	1.61	4.36	4.69	3.72	6.11	42.90
1994	5.78	4.04	6.55	2.26	2.93	0.51	0.91	5.04	4.41	1.09	6.34	4.30	44.16
1995	2.93	3.74	1.53	2.52	2.79	3.12	1.78	0.54	4.91	5.97	5.83	3.74	39.40
1996	5.22	3.51	3.58	6.40	3.39	4.41	4.94	2.68	6.08	8.24	3.11	8.66	60.22
1997	3.82	2.64	5.10	4.21	2.67	2.16	2.21	3.33	1.27	2.55	5.42	4.66	40.04
1998	7.01	5.66	8.08	6.55	8.58	8.43	0.94	3.68	2.50	1.91	2.05	1.22	56.61
1999	8.85	4.81	5.32	2.35	2.41	1.04	2.12	8.71	5.90	4.78	2.58	2.85	51.72
2000	3.75	2.58	5.49	6.29	4.28	5.18	8.37	3.38	6.86	0.31	3.79	4.09	54.37
2001	3.28	2.63	10.37	2.03	4.22	6.46	3.47	4.68	4.04	1.04	0.74	2.59	45.55
2002	3.07	1.16	5.05	4.58	4.48	4.37	1.37	3.94	5.84	6.40	6.18	5.63	52.07
2003	2.48	5.74	5.99	5.11	6.07	12.28	2.38	5.19	5.22	4.80	3.63	4.22	63.11
2004	2.15	3.14	3.47	4.94	2.59	1.34	3.05	4.30	5.14	1.62	2.16	1.96	35.86
2005	3.32	2.10	2.47	2.53	2.36	1.48	2.16	0.87	1.09	22.14	5.00	4.60	50.12
2006	5.52	2.87	0.89	7.17	6.73	6.73	5.73	6.44	3.21	7.22	6.61	2.47	61.59

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2007	4.32	2.00	5.58	6.87	2.06	3.18	7.58	2.78	1.69	1.71	3.31	4.25	45.33
2008	2.36	5.57	4.67	4.01	3.61	2.28	1.97	3.07	9.31	4.02	3.82	4.37	49.06
2009	1.27	1.74	1.79	5.39	6.05	7.99	7.19	1.15	3.18	6.13	4.65	7.64	54.17
2010	2.15	6.01	11.98	0.74	3.88	1.64	6.70	2.21	4.56	3.08	2.91	4.08	49.94
2011	3.23	3.61	3.00	4.34	3.37	4.33	2.34	9.81	4.74	5.75	3.52	3.16	51.20
2012	3.01	1.27	1.11	3.81	4.53	7.74	8.26	4.57	3.49	3.24	2.49	7.30	50.82
2013	2.35	5.84	3.82	1.67	3.04	8.37	4.14	2.05	2.39	0.26	3.13	6.17	43.23
2014	2.90	5.63	6.73	4.86	4.82	2.35	2.58	3.67	2.66	5.23	5.79	7.03	54.25
2015	5.15	2.98	5.87	1.81	0.53	4.38	1.69	1.54	3.53	4.23	2.41	5.25	39.37
2016	3.08	5.40	3.41	2.65	3.84	1.17	3.42	2.19	3.35	3.42	3.30	3.70	38.93
2017	5.19	2.37	6.82	4.79	4.83	4.12	3.11	4.77	3.24	6.52	2.26	2.33	50.35
2018	4.25	6.71	8.04	4.39	3.73	2.43	3.74	7.67	4.81	6.50	9.16	7.10	68.53
2019	4.74	3.62	3.37	6.95	6.19	3.95	2.62	2.15	1.18	6.84	2.05	8.44	52.10
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Average	4.03	3.82	4.85	4.19	3.85	3.70	3.47	4.38	3.70	4.09	4.35	4.65	49.02
Max	13.01	6.71	11.98	11.09	10.47	12.85	8.62	11.98	10.47	22.14	9.16	8.66	68.66
Min	0.62	1.16	0.89	0.74	0.53	0.42	0.50	0.54	0.86	0.18	0.54	0.82	34.35

Min Max

## Wind Direction and Wind Speed

Wind speed and direction are recorded via R.M. Young 5106 marine grade mechanical wind sensor. This unit has a 0 to 100 m/s wind speed range and has been modified to have a 0.5 m/s wind speed threshold sensitivity. Accuracy is  $\pm 0.3$  m/s. The direction sensor has a 355° electrical range and 360° mechanical. Direction accuracy is  $\pm 3^\circ$  and sensitivity is 1.1 m/s (wind speed needed for accurate measurement). These units require a wind tunnel calibration and are sent out for calibration on an annual basis. Enough spare units are stocked to allow change out without data loss.

Average daily wind speed recorded at the 10-meter and 85-meter locations is given in Figure 59. Historic (Figures 60-61), Annual (Figures 62-64) and Monthly (Figures 65-100) wind roses are presented in Figures 58 through 95. A wind rose is a graphic tool used by meteorologists to give a succinct view of how wind speed and direction are typically distributed at a particular location. The wind rose data used in the plots are generated from hourly averages. Wind roses are presented for the 10-, 50- and 85-meter locations. Speed bins are 0.3 to 2.5 m/s, 2.5 to 5 m/s, 5 to 7.5 m/s, 7.5 to 10 m/s and >10 m/s. Percent calm data (<0.3 m/s) and percent bad data are also listed. Prevailing winds at BNL are from the south-southwest with a secondary west-northwest component at the 85 meter level and west-northwest with a secondary south-southwest component at the 10 meter level.

Figures 101 through 124 present the 1-minute data for wind speed and wind gust. Plots contain data from 10-, 50- and 85-meters.

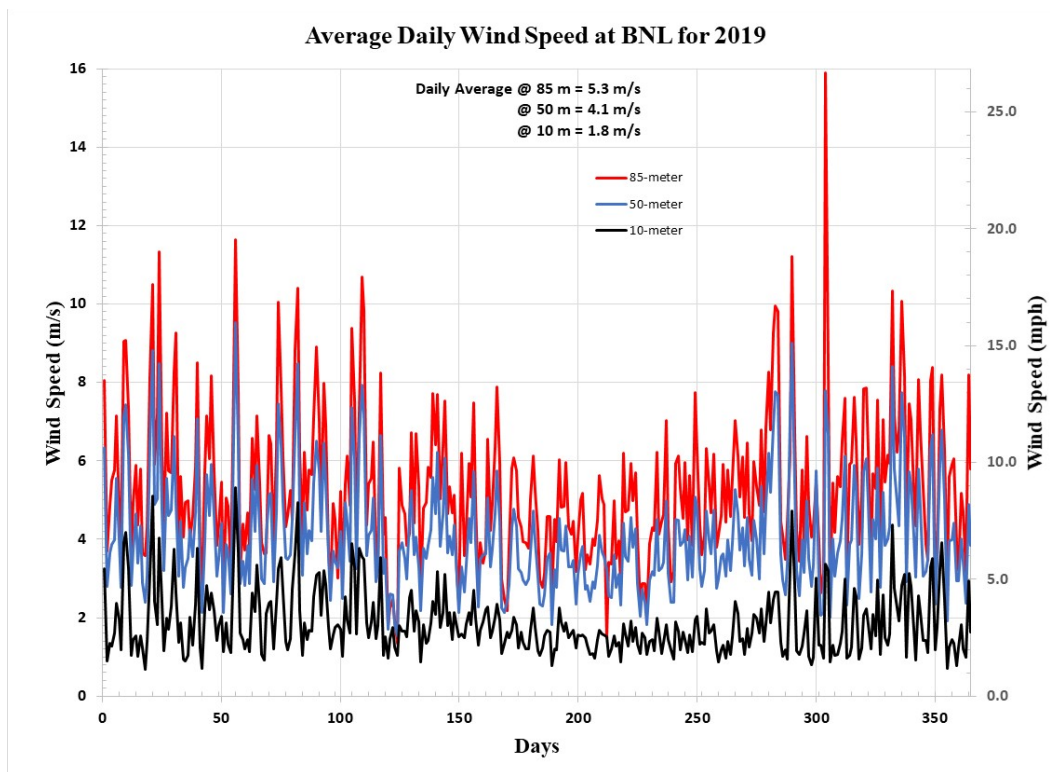


Figure 59      Average Daily Wind Speed (m/s) at the 10-meter, 50-meter and 85-meter heights at Brookhaven National Laboratory for 2019

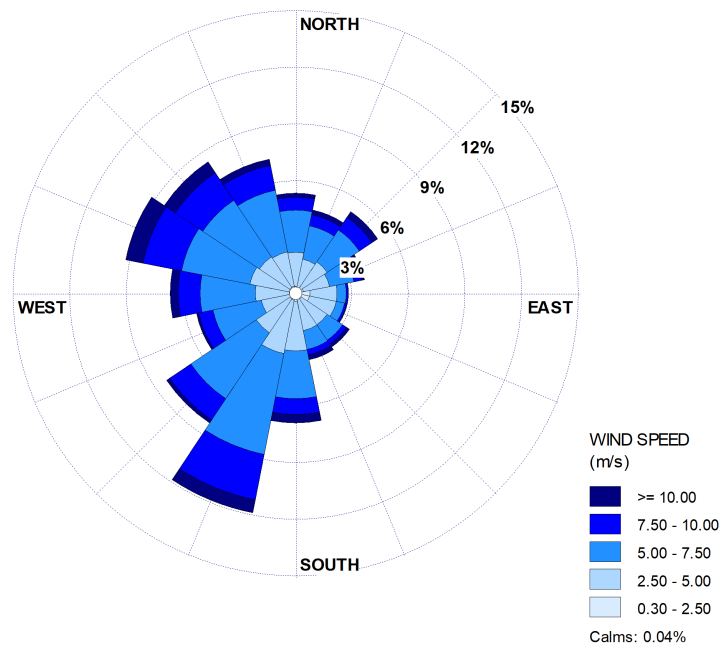


Figure 60 Historic Annual One-hour Wind Roses for the Years 1994 to 2019 from the 85m level

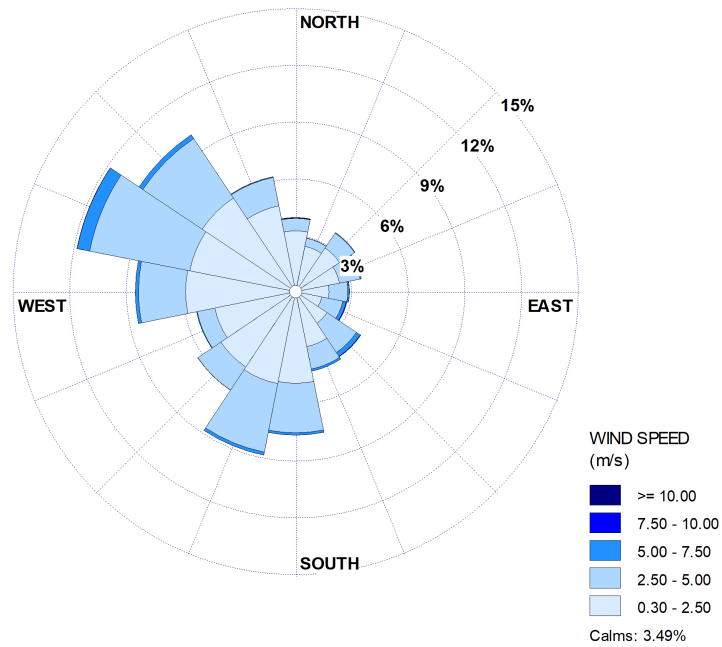


Figure 61 Historic Annual One-hour Wind Roses for the Years 1994 to 2019 from the 10m level

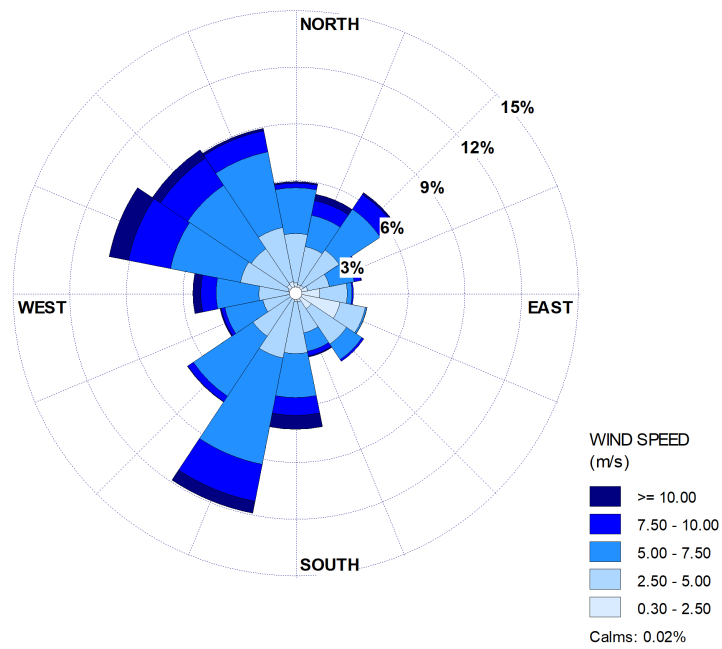


Figure 62 Annual One-hour Wind Roses for the Year 2019 from the 85m level

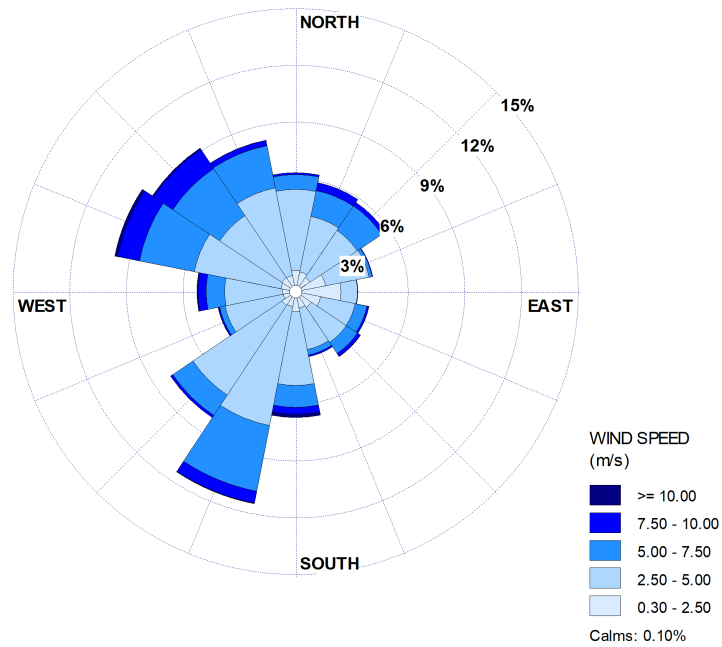


Figure 63 Annual One-hour Wind Roses for the Year 2019 from the 50m level

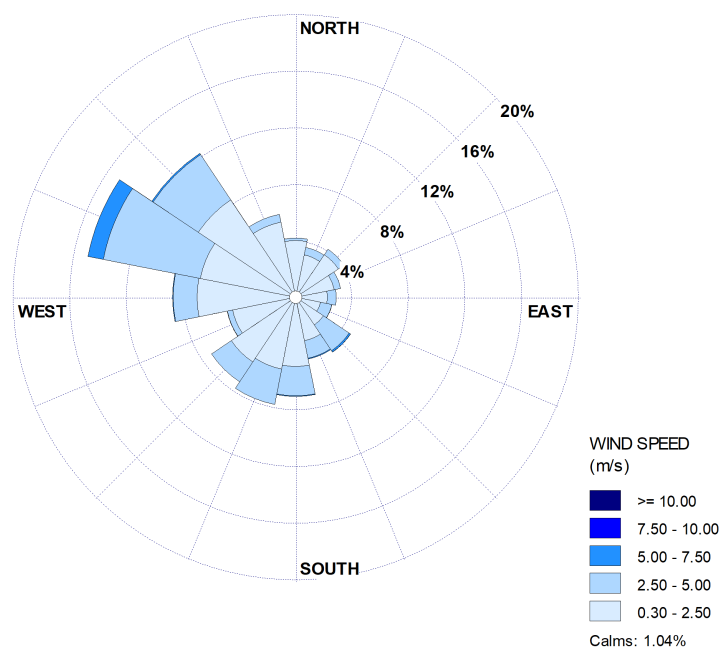


Figure 64 Annual One-hour Wind Roses for the Year 2019 from the 10m level

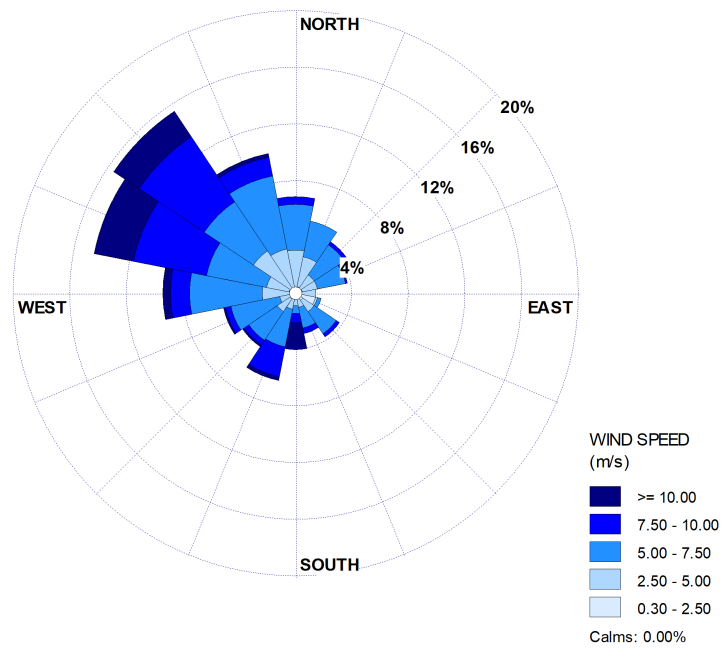


Figure 65 One-hour Wind Roses for the Month of January 2019 from the 85m level

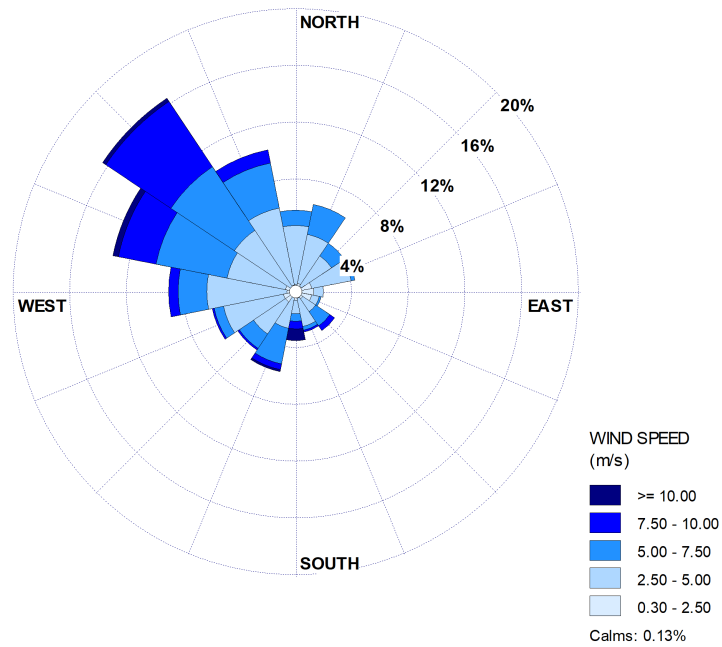


Figure 66 One-hour Wind Roses for the Month of January 2019 from the 50m level

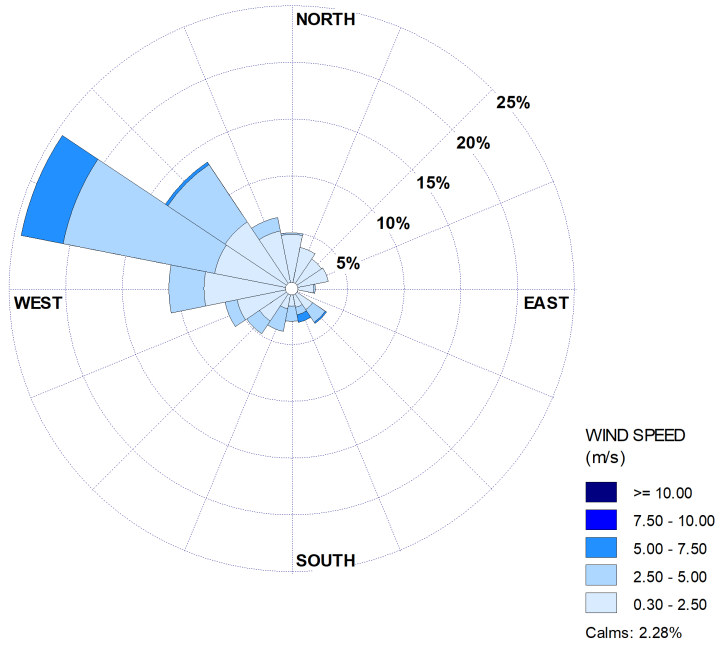


Figure 67 One-hour Wind Roses for the Month of January 2019 from the 10m level

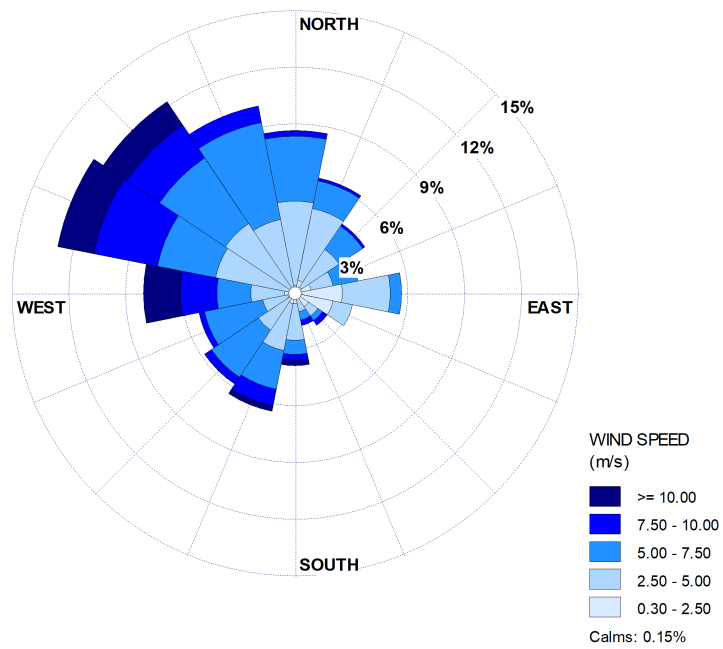


Figure 68 One-hour Wind Roses for the Month of February 2019 from the 85m level

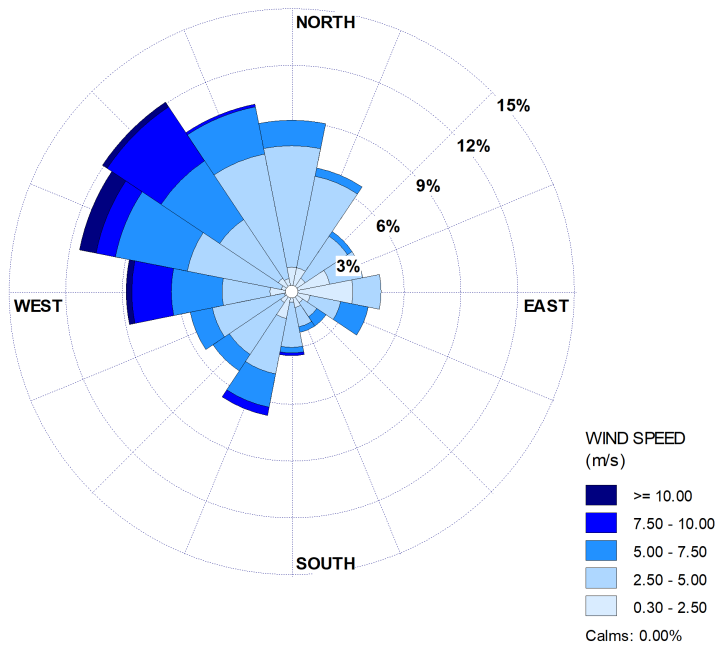


Figure 69 One-hour Wind Roses for the Month of February 2019 from the 50m level

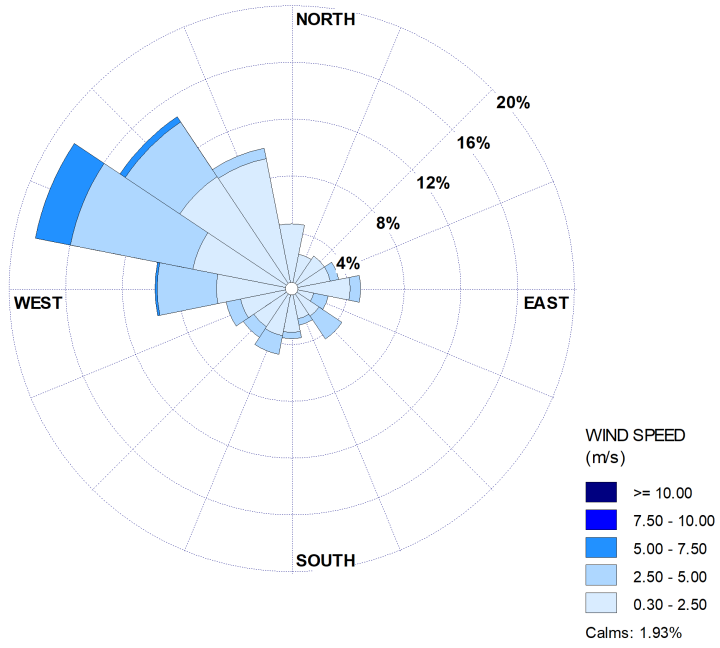


Figure 70 One-hour Wind Roses for the Month of February 2019 from the 10m level

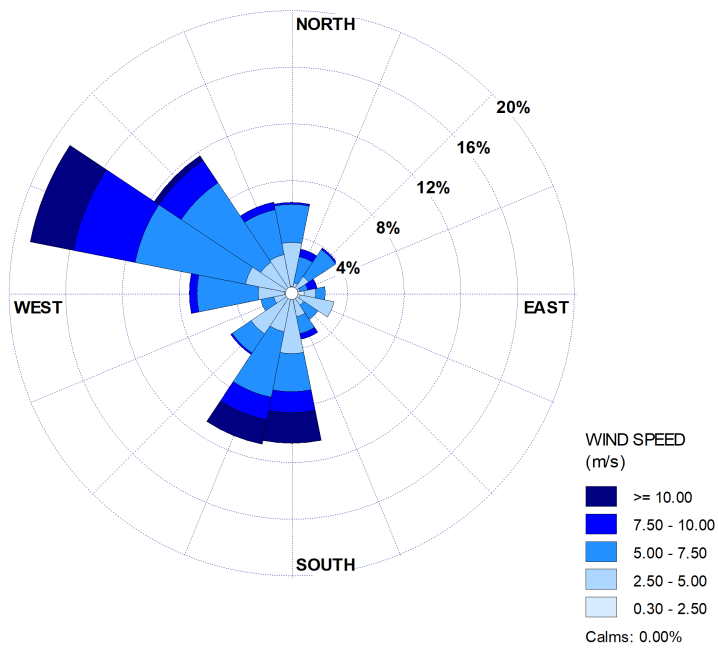


Figure 71 One-hour Wind Roses for the Month of March 2019 from the 85m level

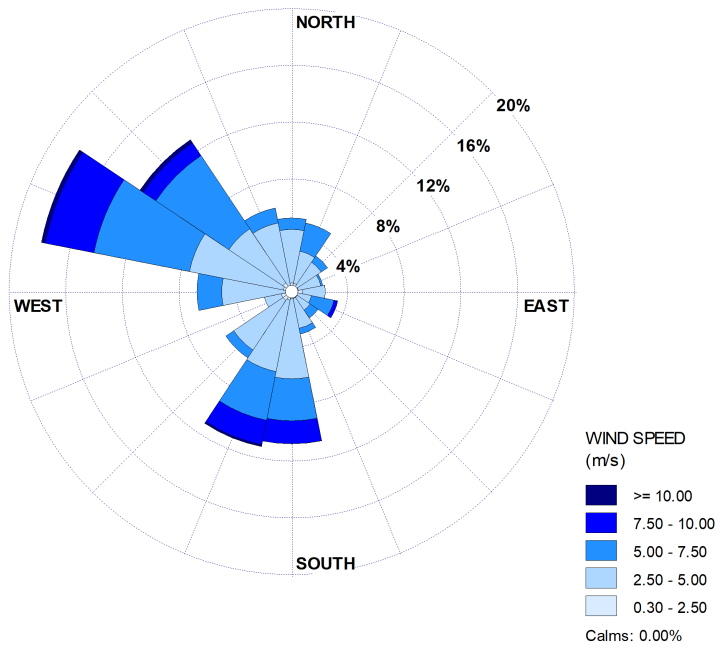


Figure 72 One-hour Wind Roses for the Month of March 2019 from the 50m level

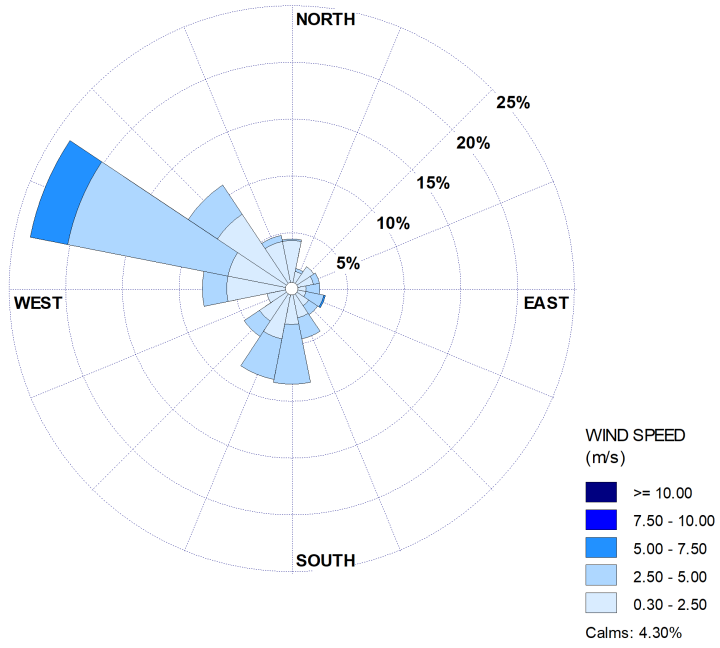


Figure 73 One-hour Wind Roses for the Month of March 2019 from the 10m level

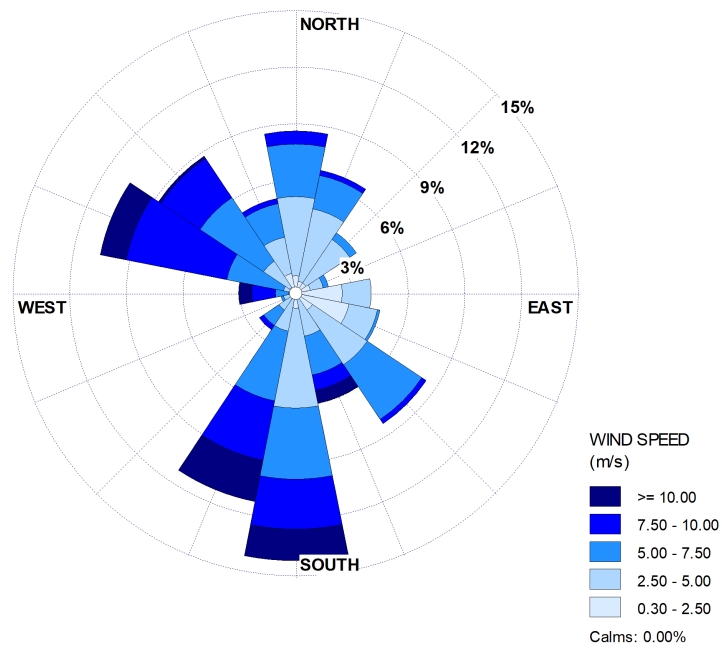


Figure 74 One-hour Wind Roses for the Month of April 2019 from the 85m level

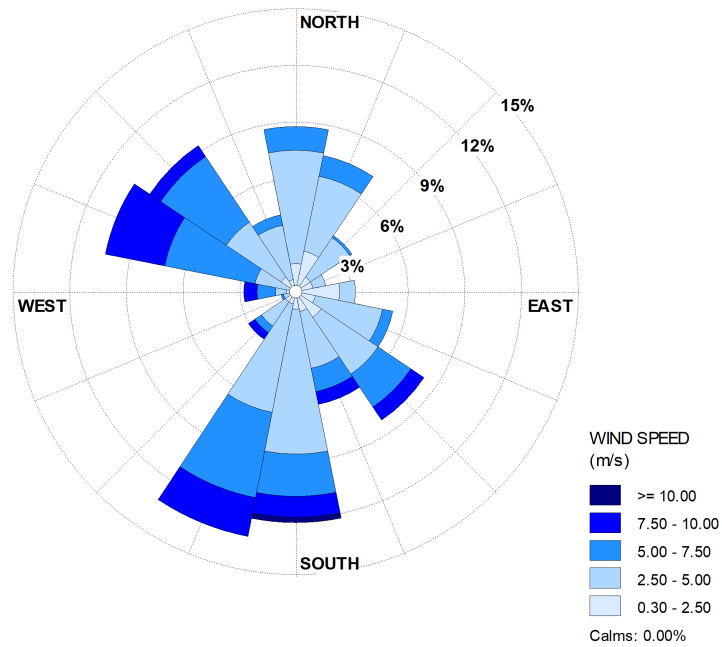


Figure 75 One-hour Wind Roses for the Month of April 2019 from the 50m level

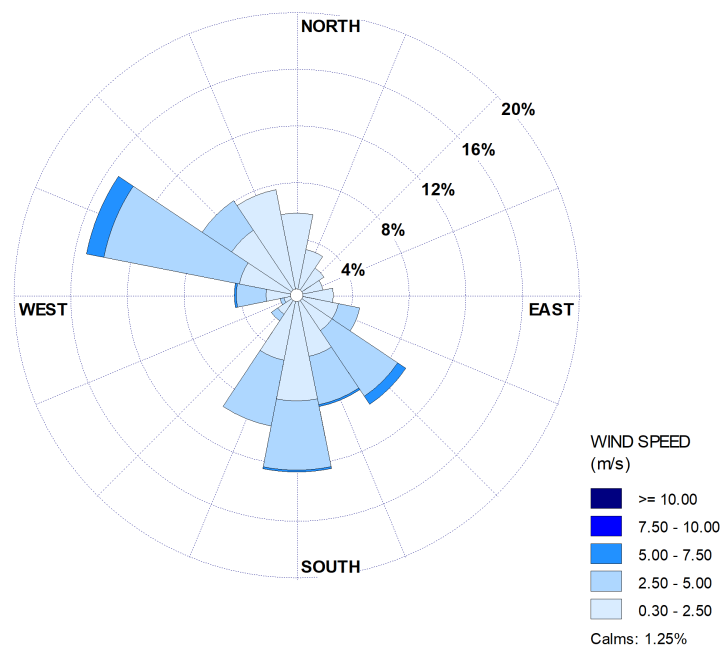


Figure 76 One-hour Wind Roses for the Month of April 2019 from the 10m level

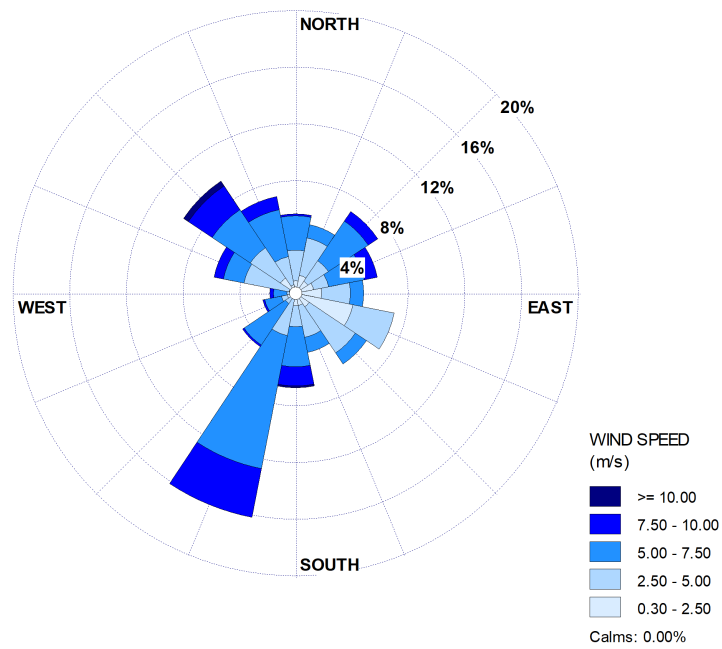


Figure 77 One-hour Wind Roses for the Month of May 2019 from the 85m level

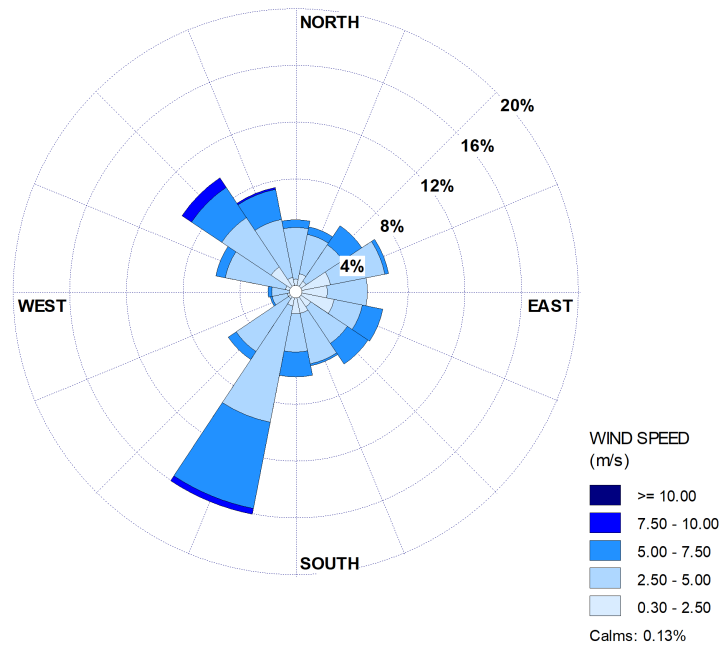


Figure 78 One-hour Wind Roses for the Month of May 2019 from the 50m level

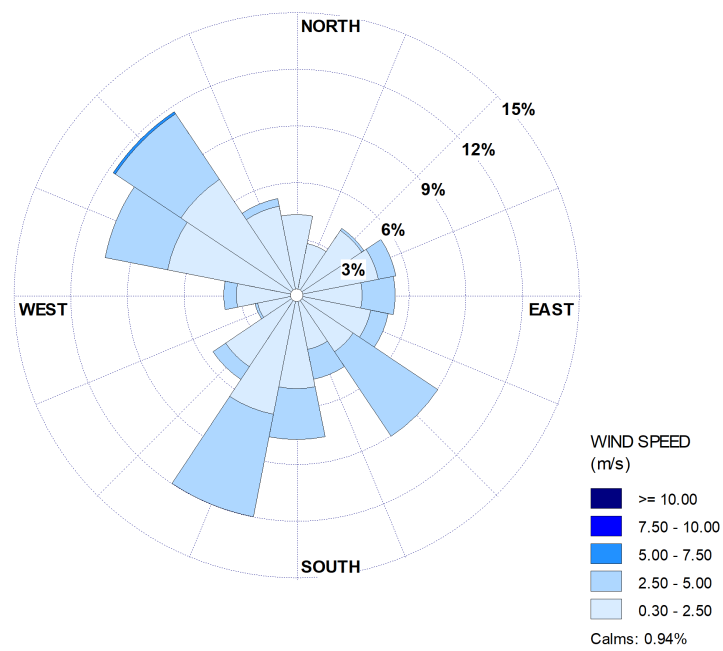


Figure 79 One-hour Wind Roses for the Month of May 2019 from the 10m level

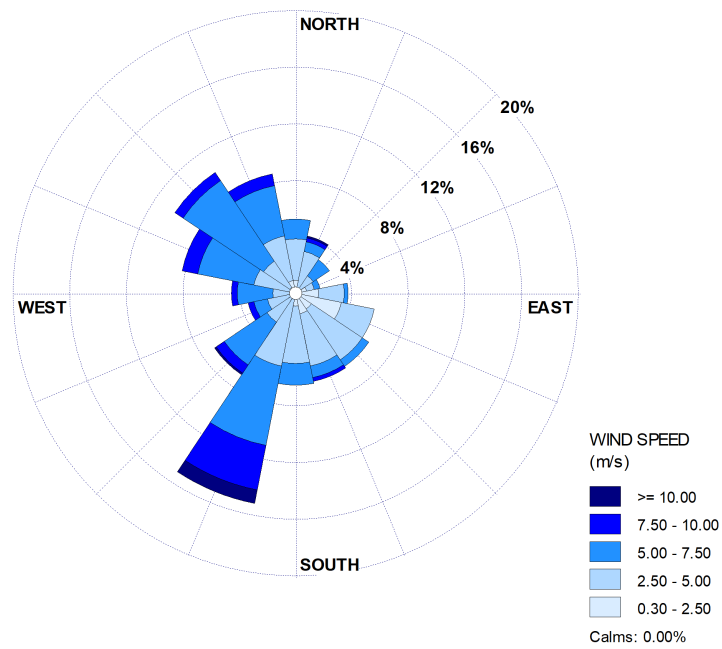


Figure 80 One-hour Wind Roses for the Month of June 2019 from the 85m level

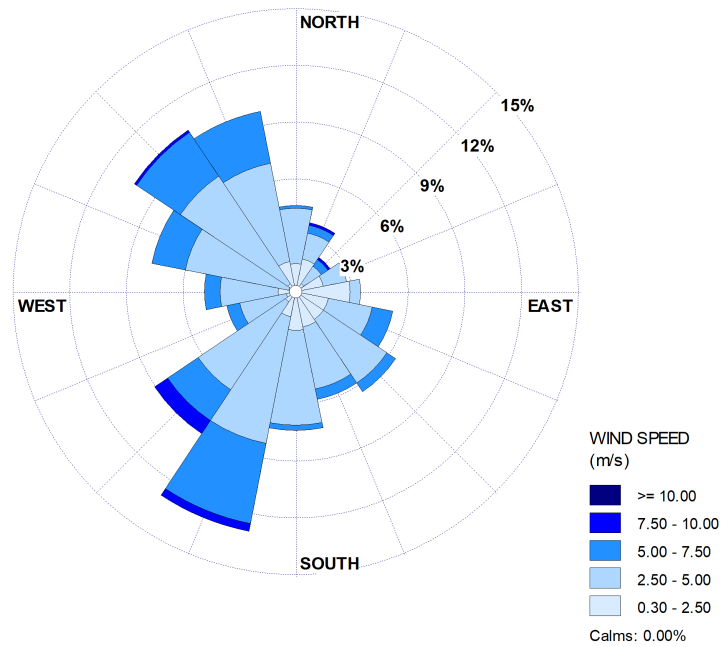


Figure 81 One-hour Wind Roses for the Month of June 2019 from the 50m level

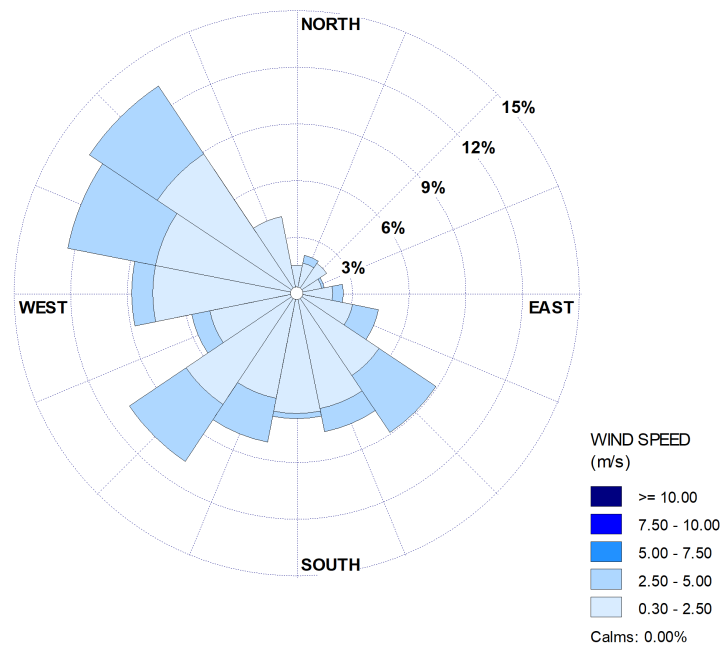


Figure 82 One-hour Wind Roses for the Month of June 2019 from the 10m level

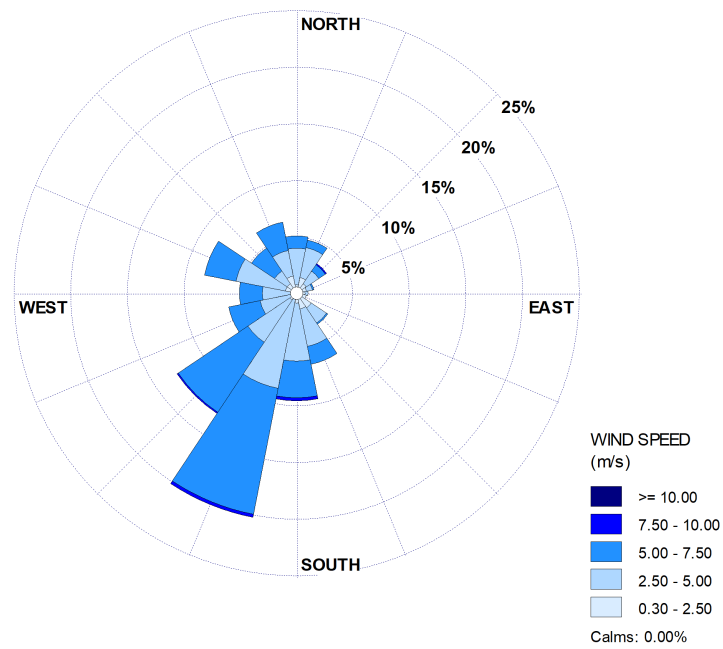


Figure 83 One-hour Wind Roses for the Month of July 2019 from the 85m level

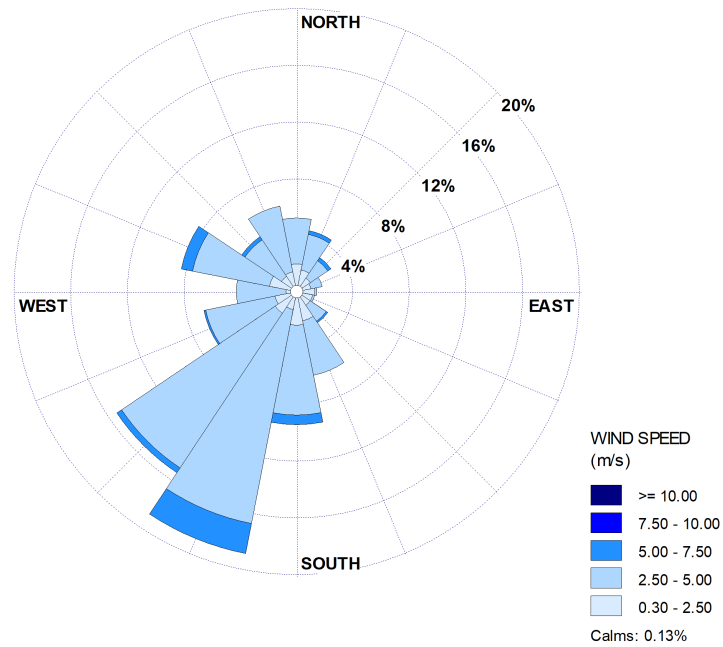


Figure 84 One-hour Wind Roses for the Month of July 2019 from the 50m level

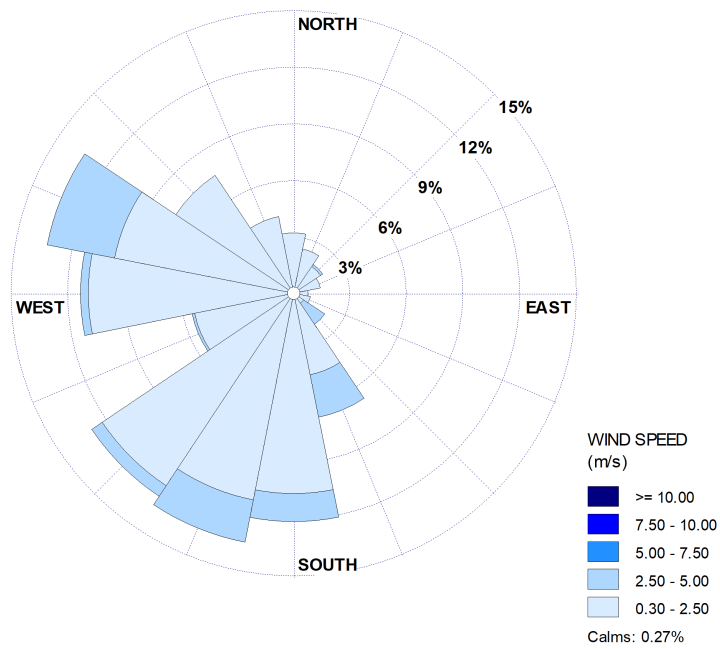


Figure 85 One-hour Wind Roses for the Month of July 2019 from the 10m level

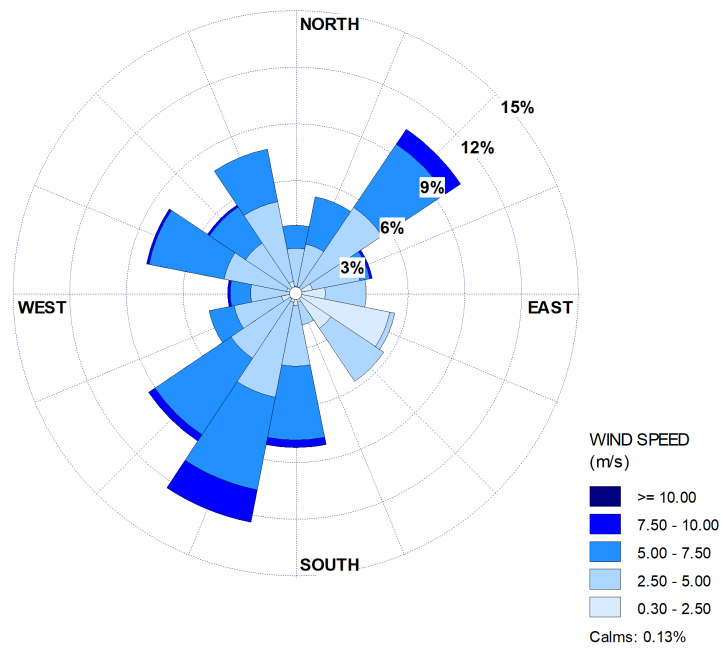


Figure 86 One-hour Wind Roses for the Month of August 2019 from the 85m level

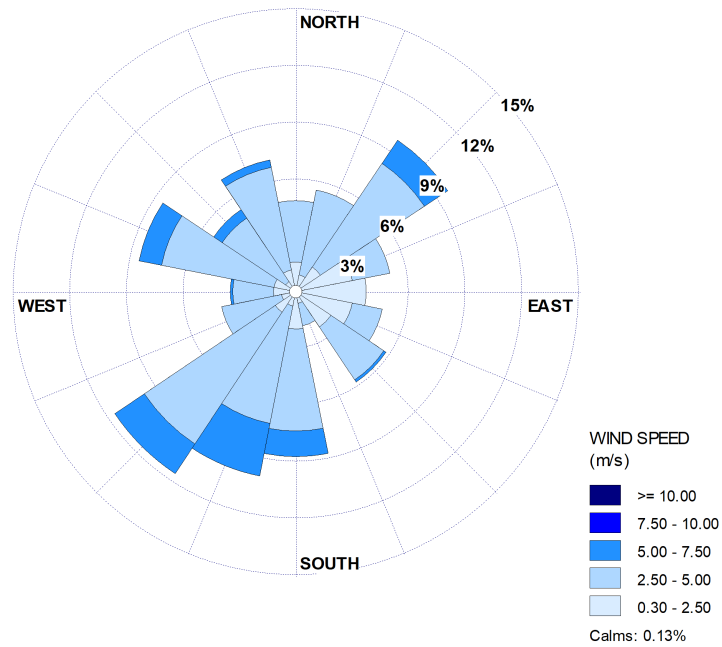


Figure 87 One-hour Wind Roses for the Month of August 2019 from the 50m level

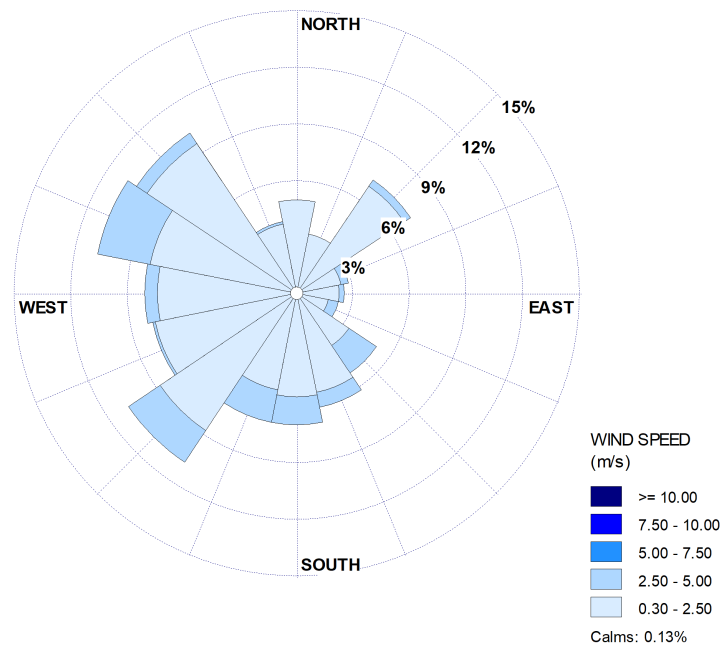


Figure 88 One-hour Wind Roses for the Month of August 2019 from the 10m level

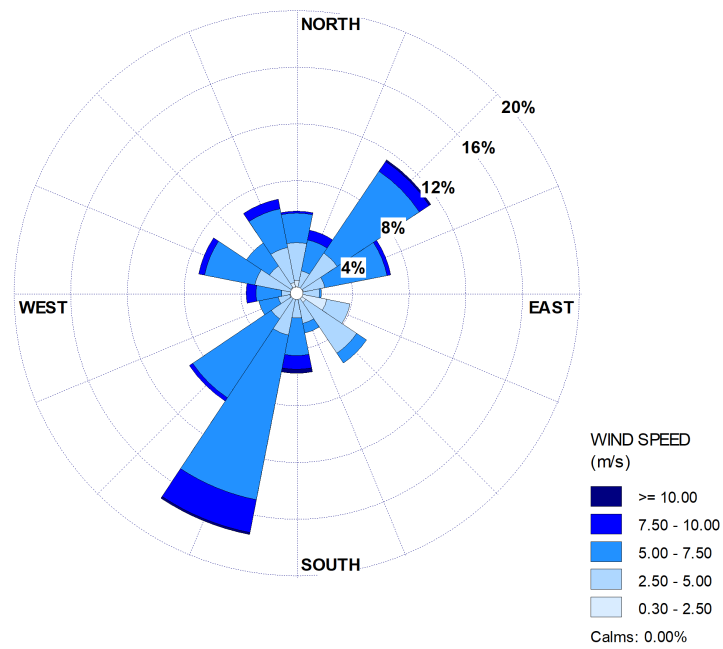


Figure 89 One-hour Wind Roses for the Month of September 2019 from the 85m level

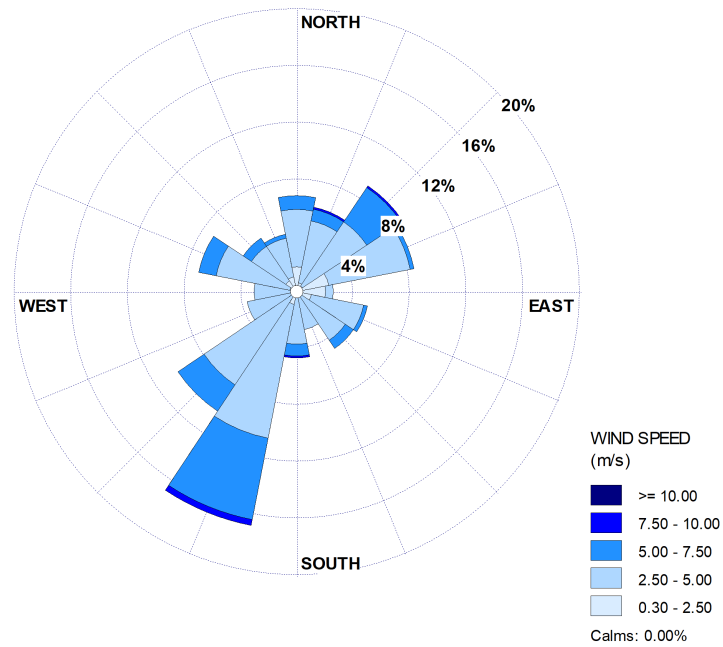


Figure 90 One-hour Wind Roses for the Month of September 2019 from the 50m level

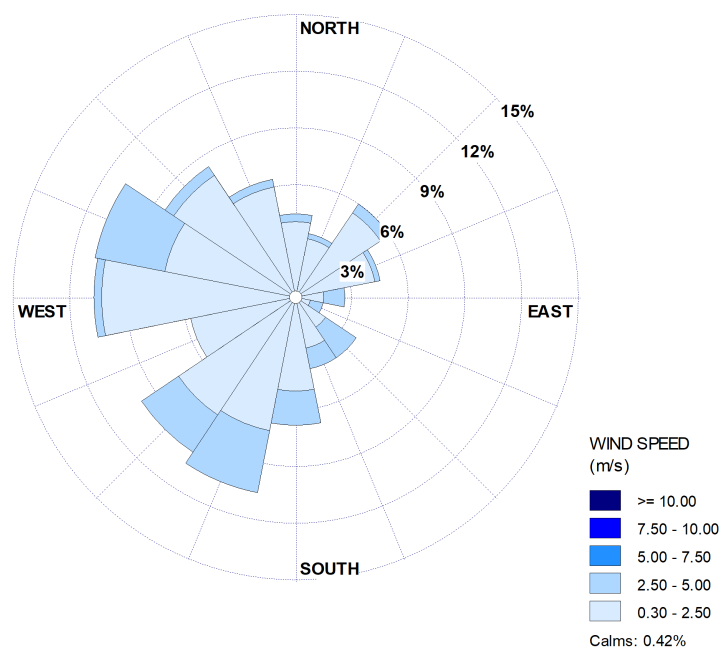


Figure 91 One-hour Wind Roses for the Month of September 2019 from the 10m level

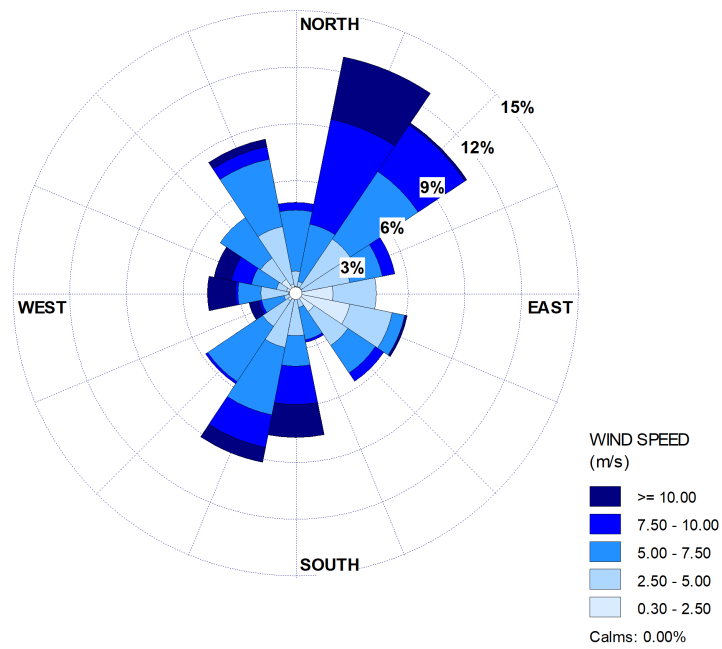


Figure 92 One-hour Wind Roses for the Month of October 2019 from the 85m level

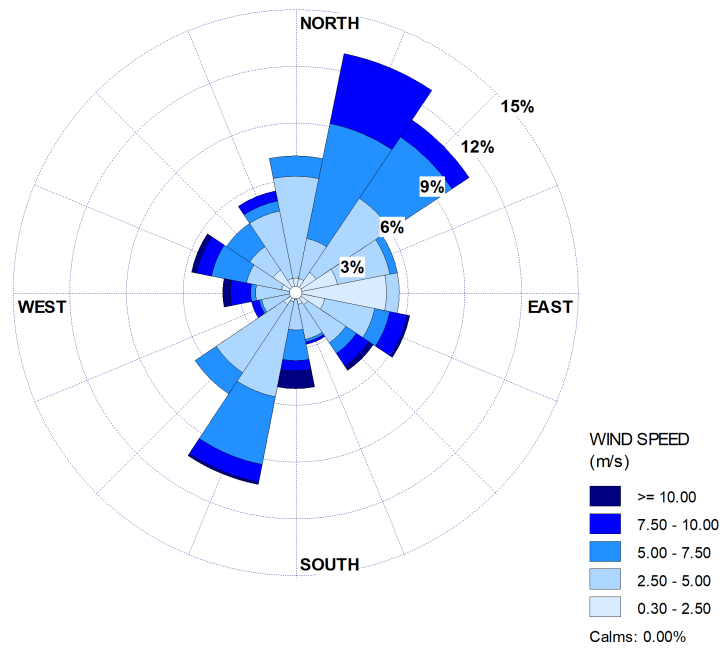


Figure 93 One-hour Wind Roses for the Month of October 2019 from the 50m level

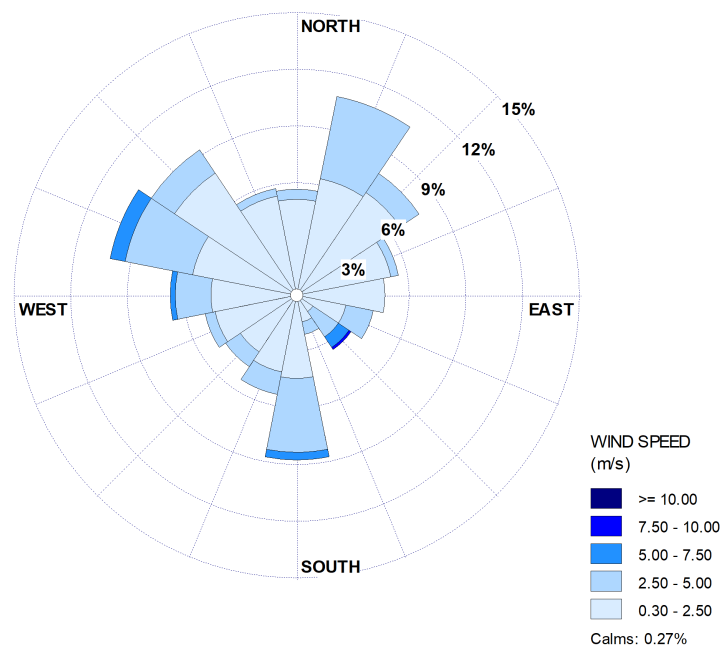


Figure 94 One-hour Wind Roses for the Month of October 2019 from the 10m level

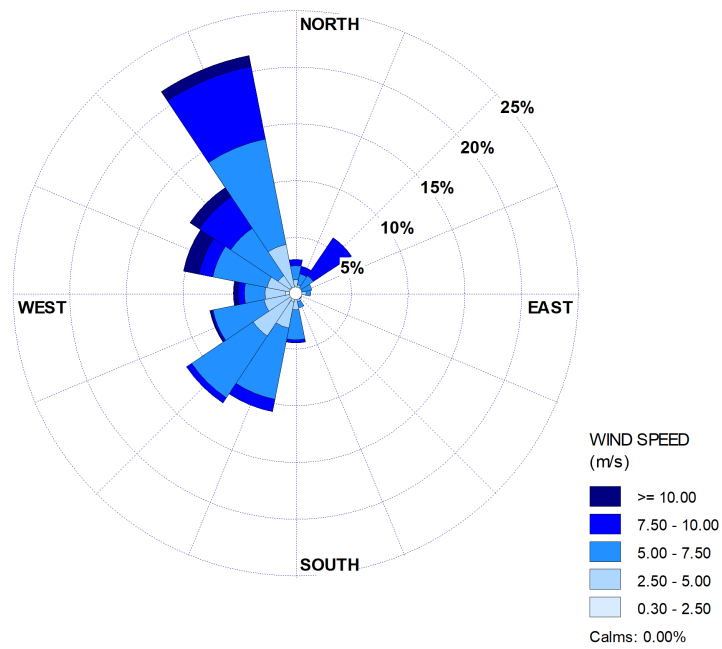


Figure 95 One-hour Wind Roses for the Month of November 2019 from the 85m level

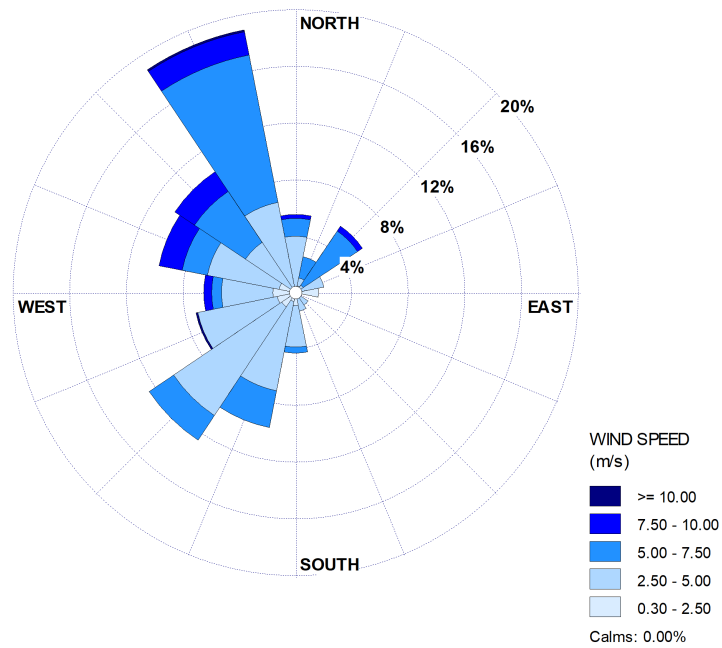


Figure 96 One-hour Wind Roses for the Month of November 2019 from the 50m level

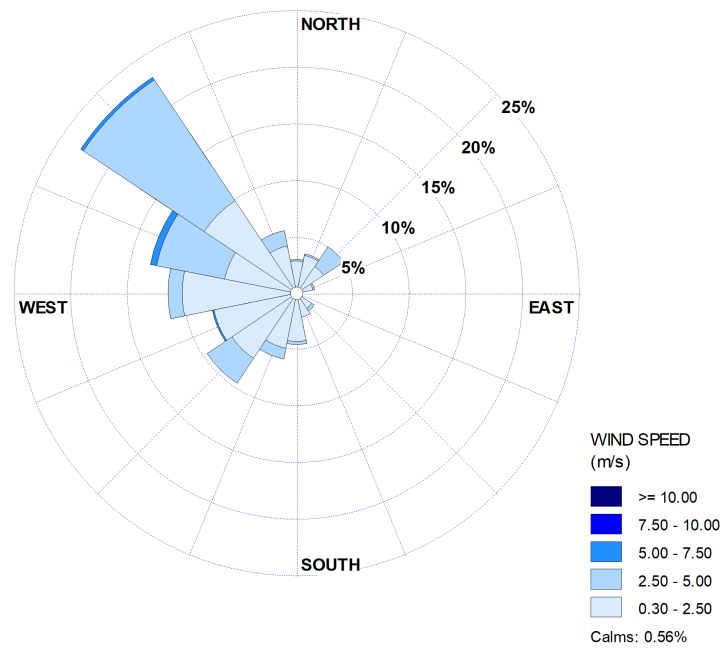


Figure 97 One-hour Wind Roses for the Month of November 2019 from the 10m level

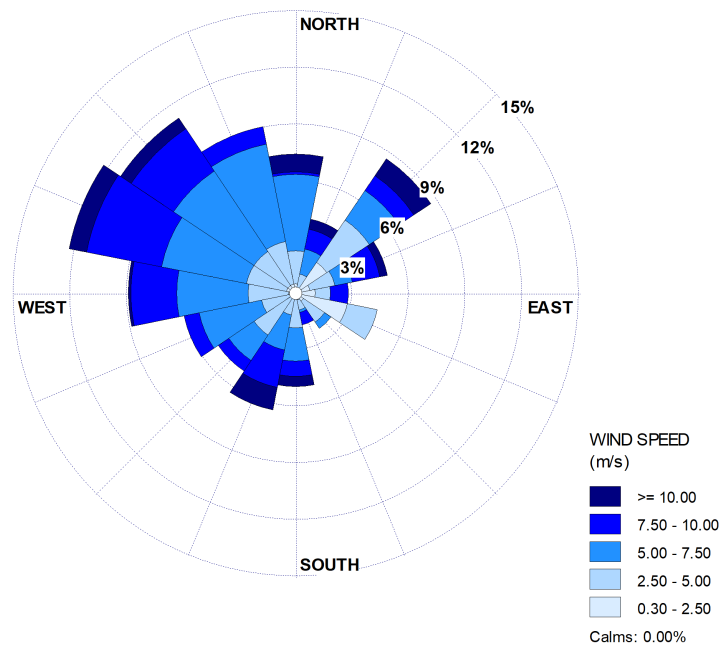


Figure 98 One-hour Wind Roses for the Month of December 2019 from the 85m level

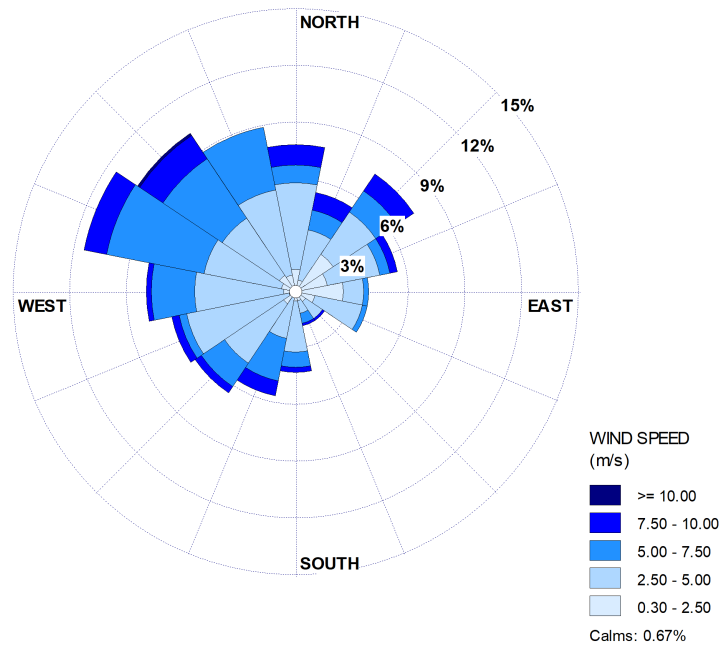


Figure 99 One-hour Wind Roses for the Month of December 2019 from the 50m level

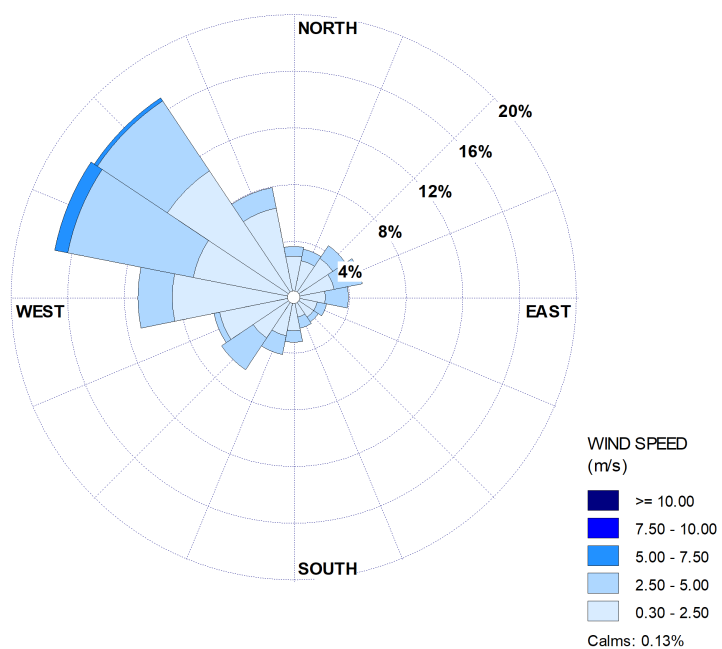


Figure 100 One-hour Wind Roses for the Month of December 2019 from the 10m level

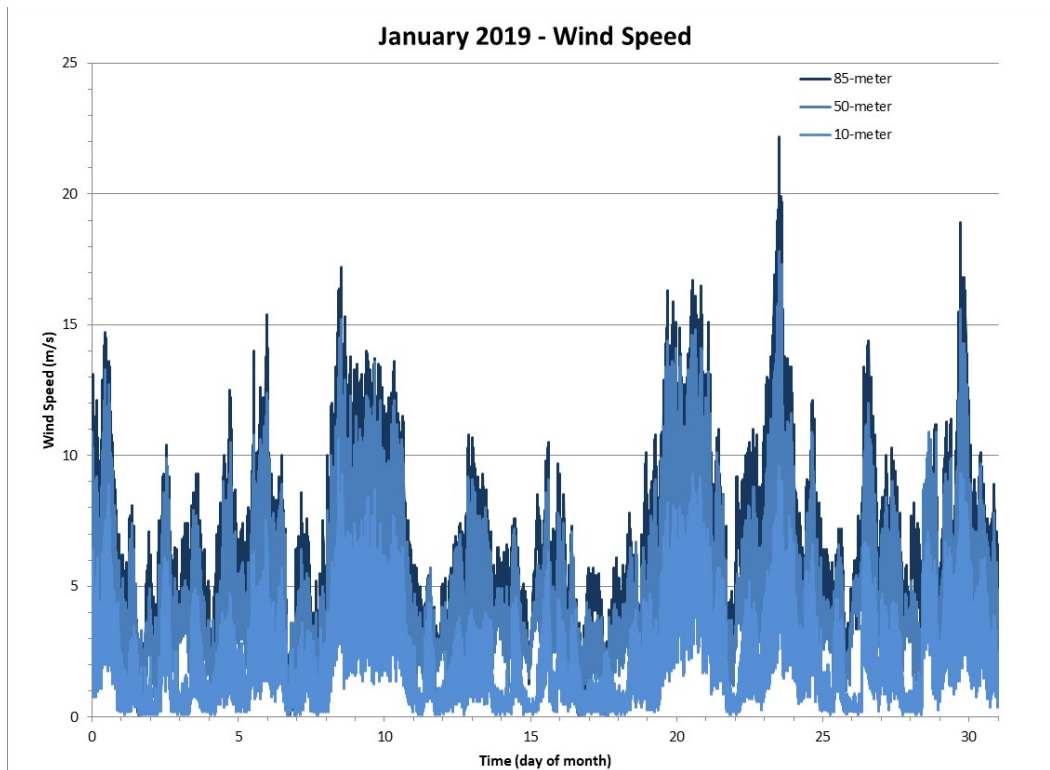


Figure 101 Wind Speed for the Month of January 2019

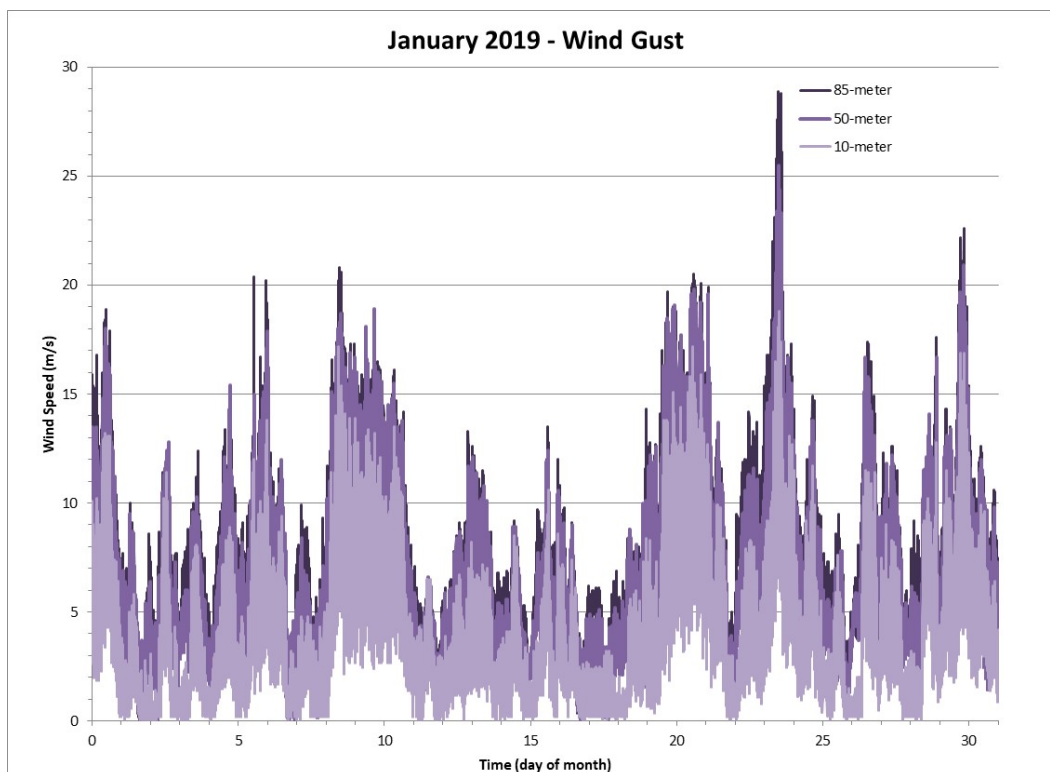


Figure 102 Wind Gust data for the Month of January 2019

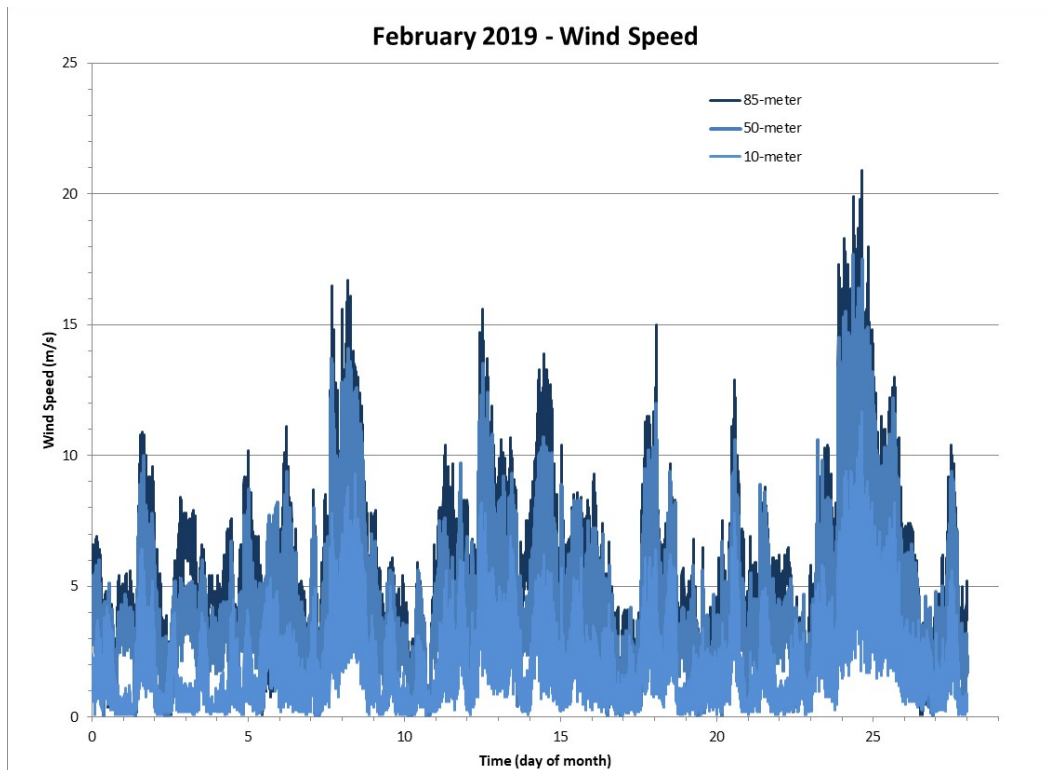


Figure 103 Wind Speed for the Month of February 2019

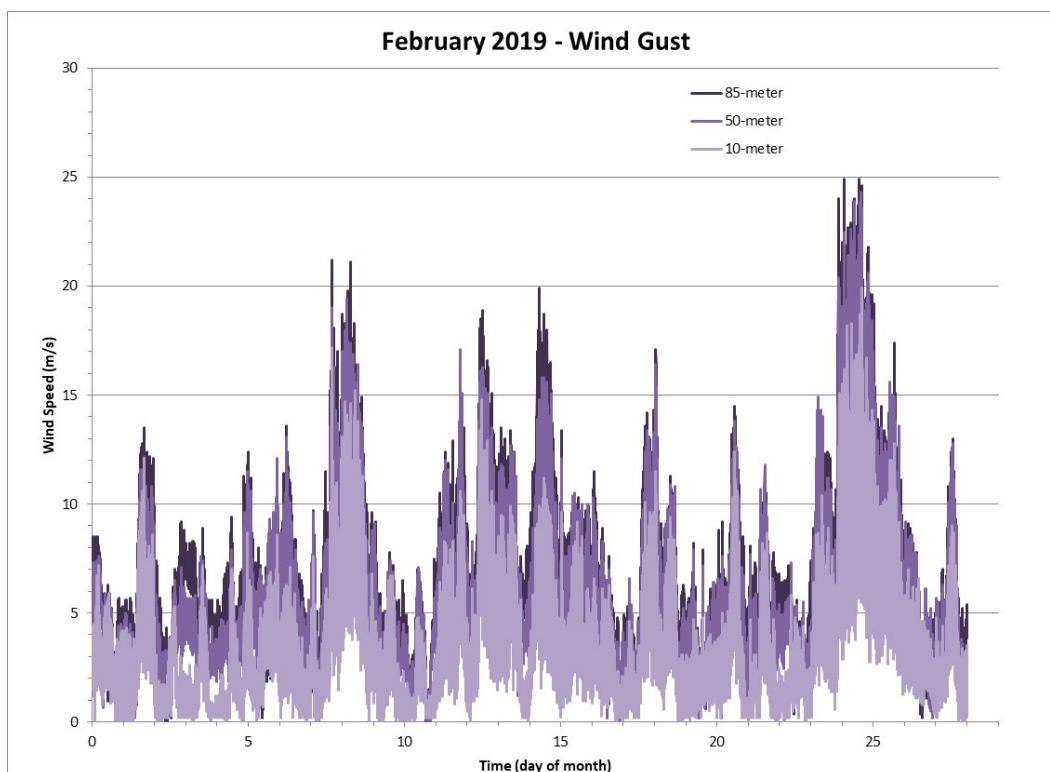


Figure 104 Wind Gust data for the Month of February 2019

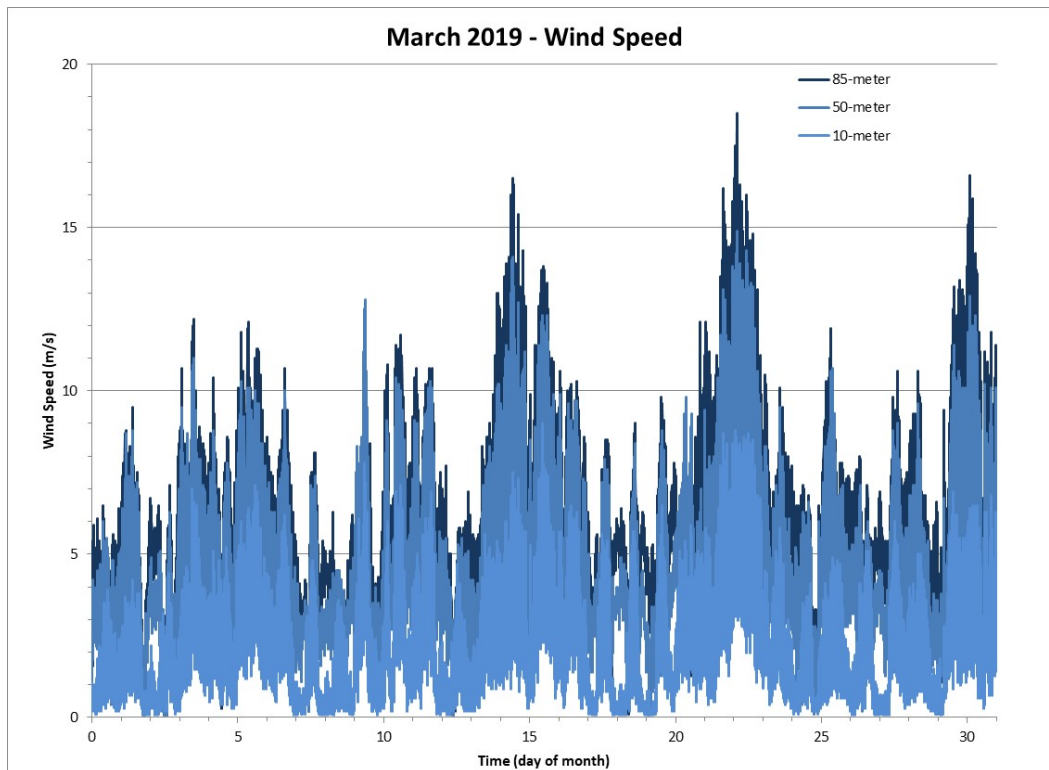


Figure 105 Wind Speed for the Month of March 2019

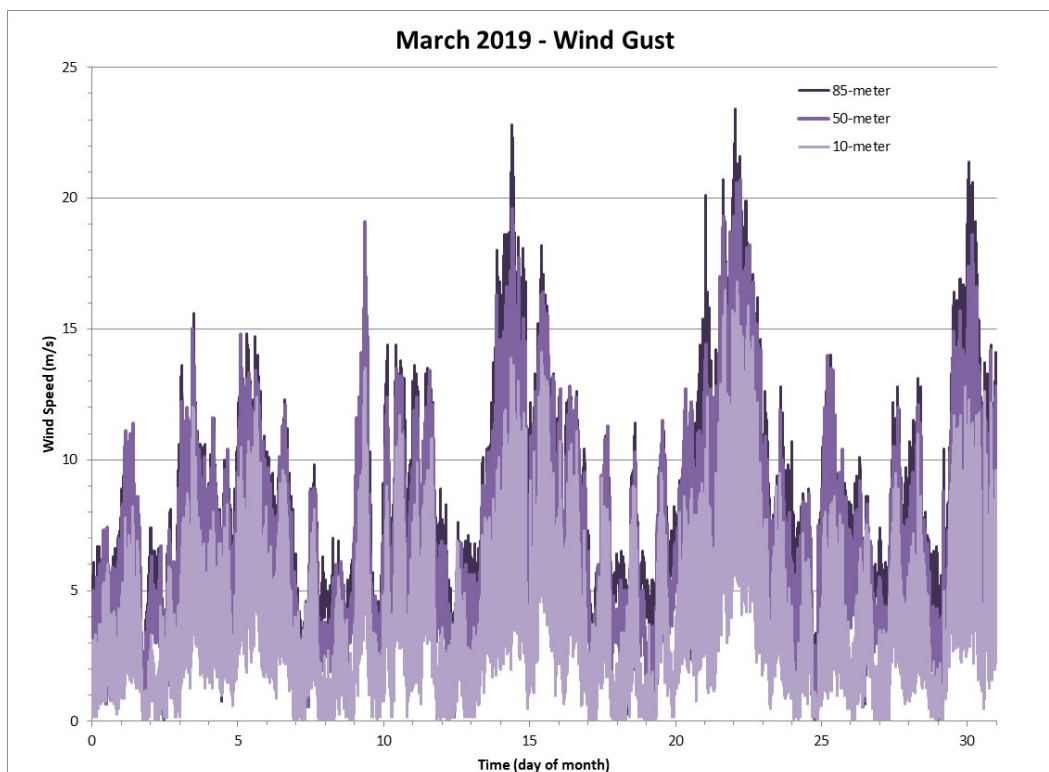


Figure 106 Wind Gust data for the Month of March 2019

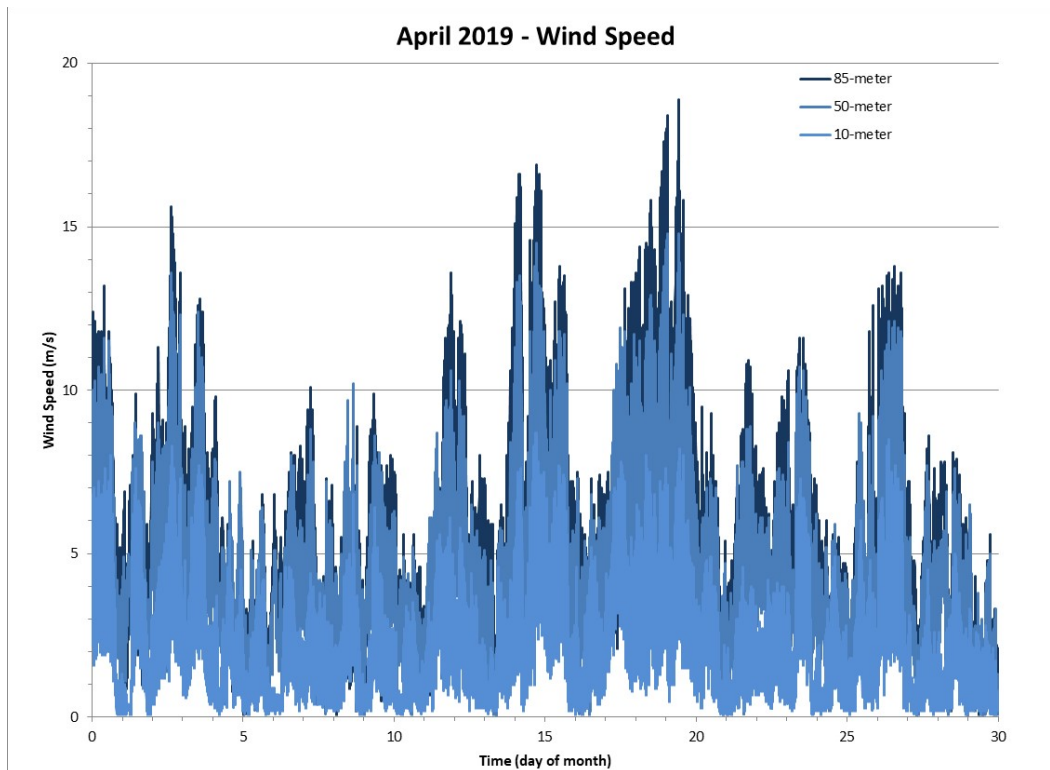


Figure 107 Wind Speed for the Month of April 2019

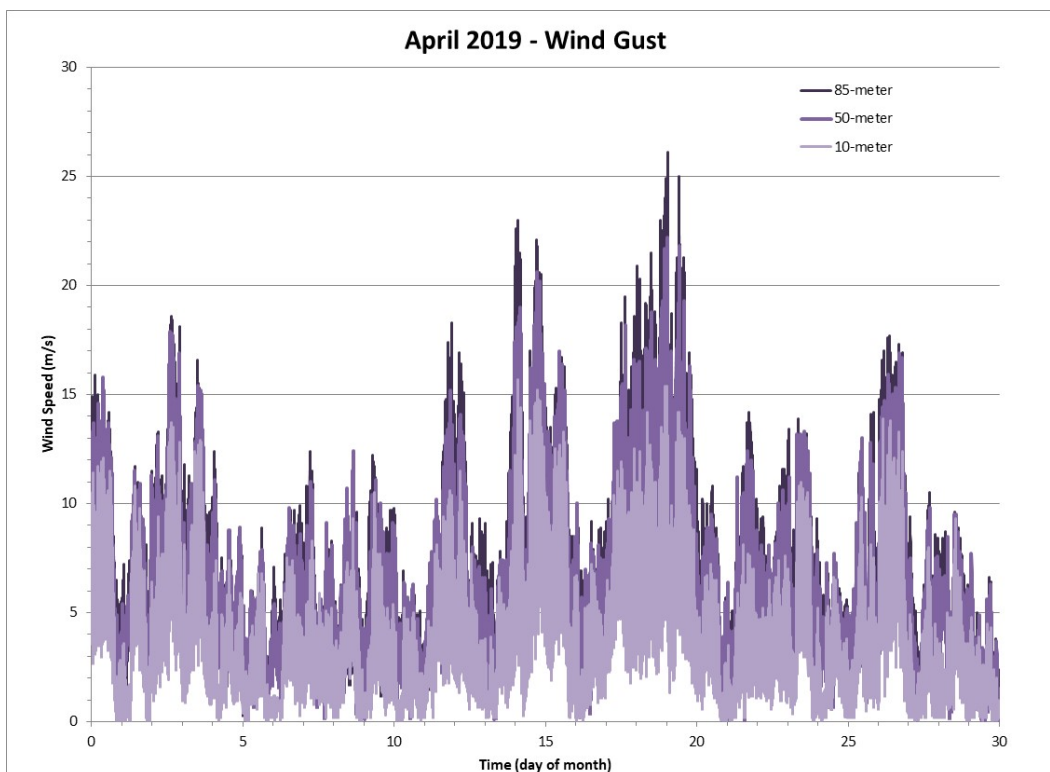


Figure 108 Wind Gust data for the Month of April 2019

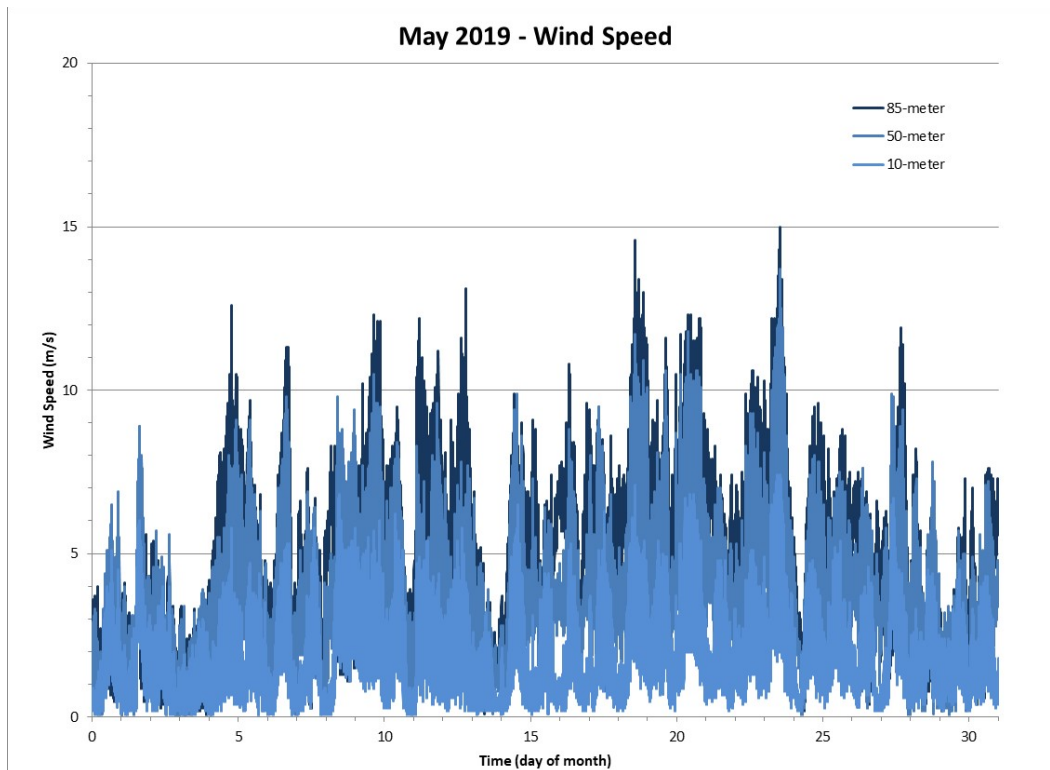


Figure 109 Wind Speed for the Month of May 2019

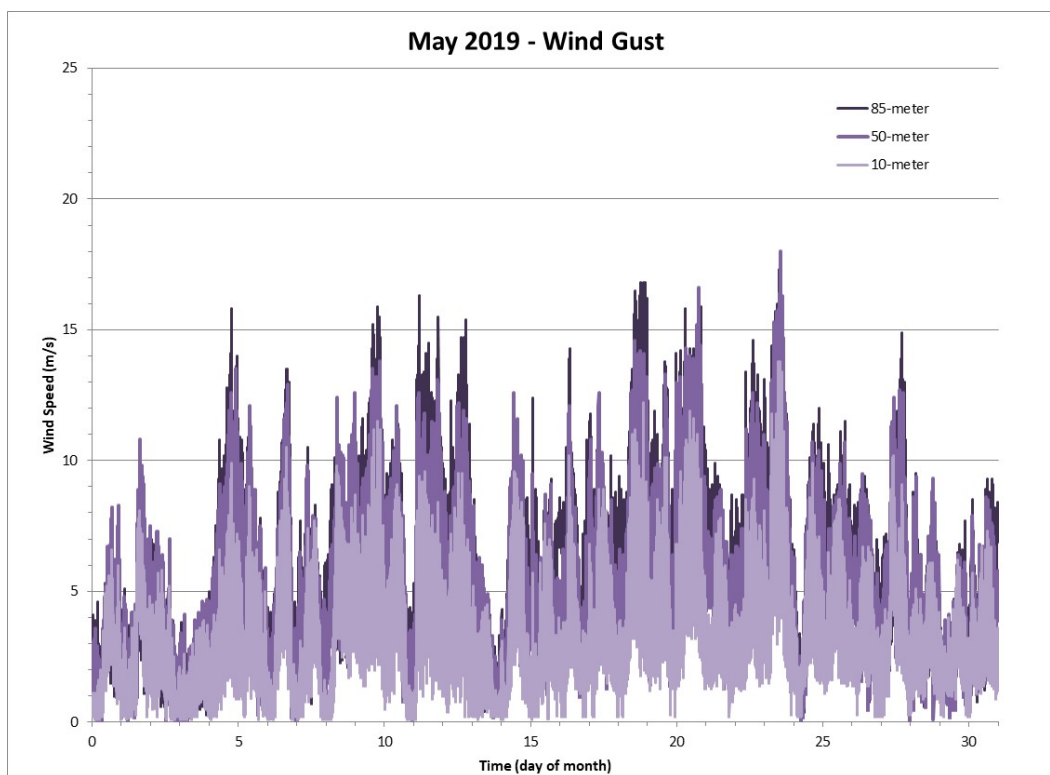


Figure 110 Wind Gust data for the Month of May 2019

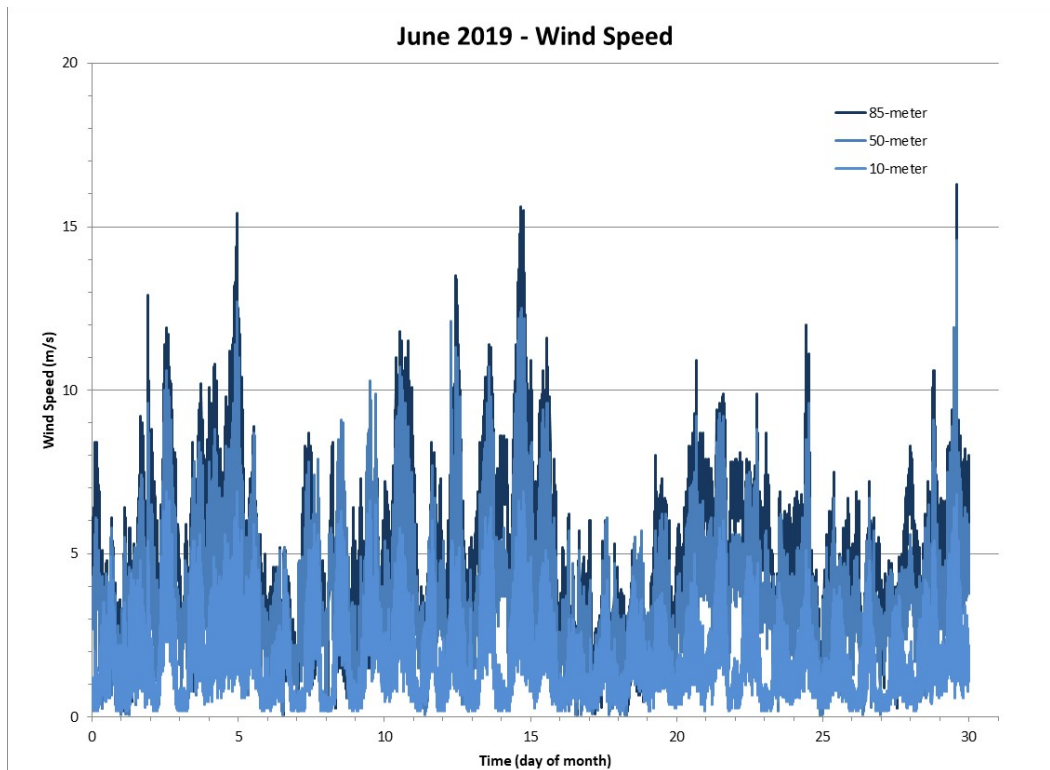


Figure 111 Wind Speed for the Month of June 2019

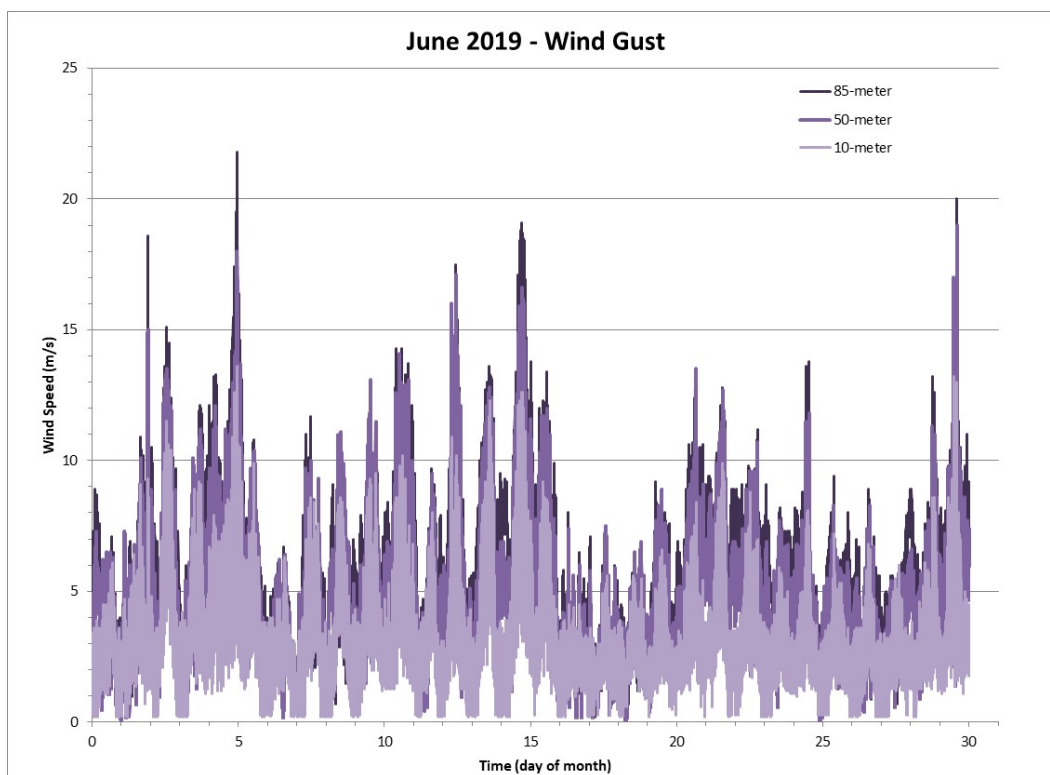


Figure 112 Wind Gust data for the Month of June 2019

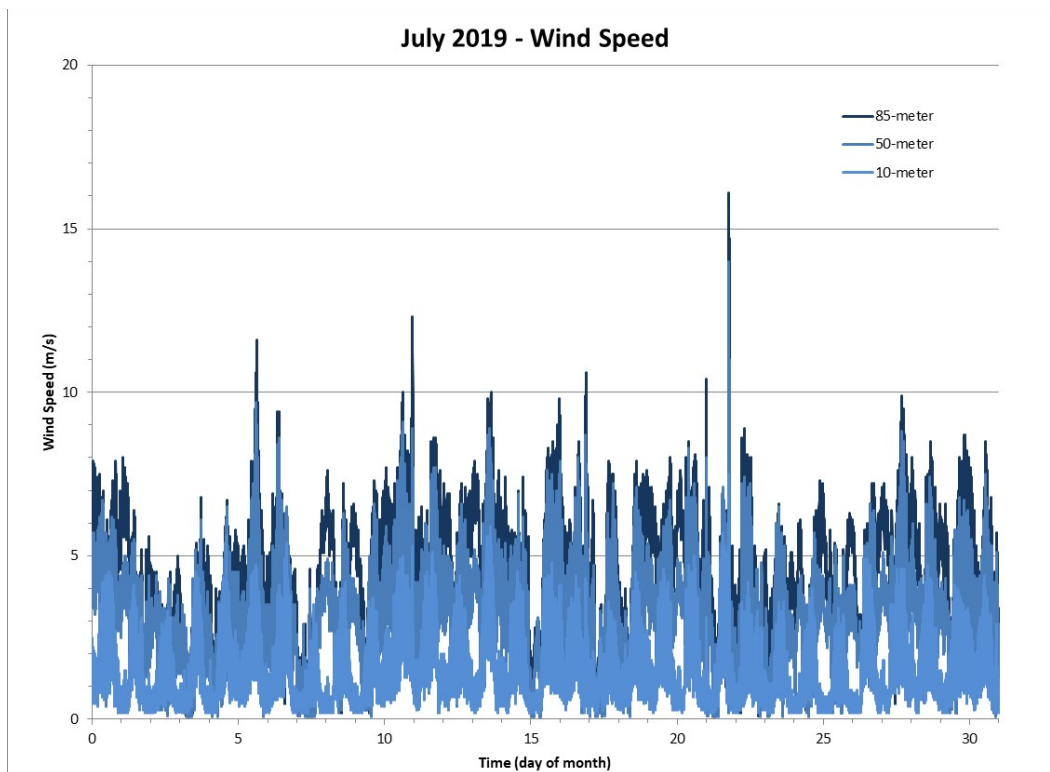


Figure 113 Wind Speed for the Month of July 2019

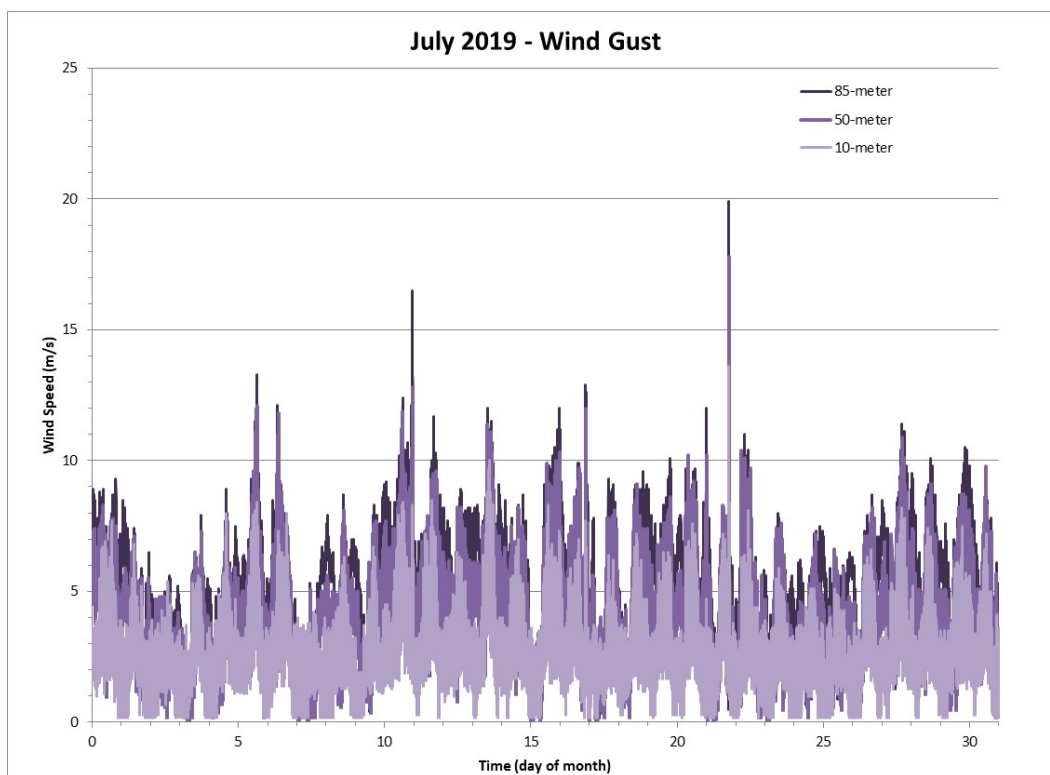


Figure 114 Wind Gust data for the Month of July 2019

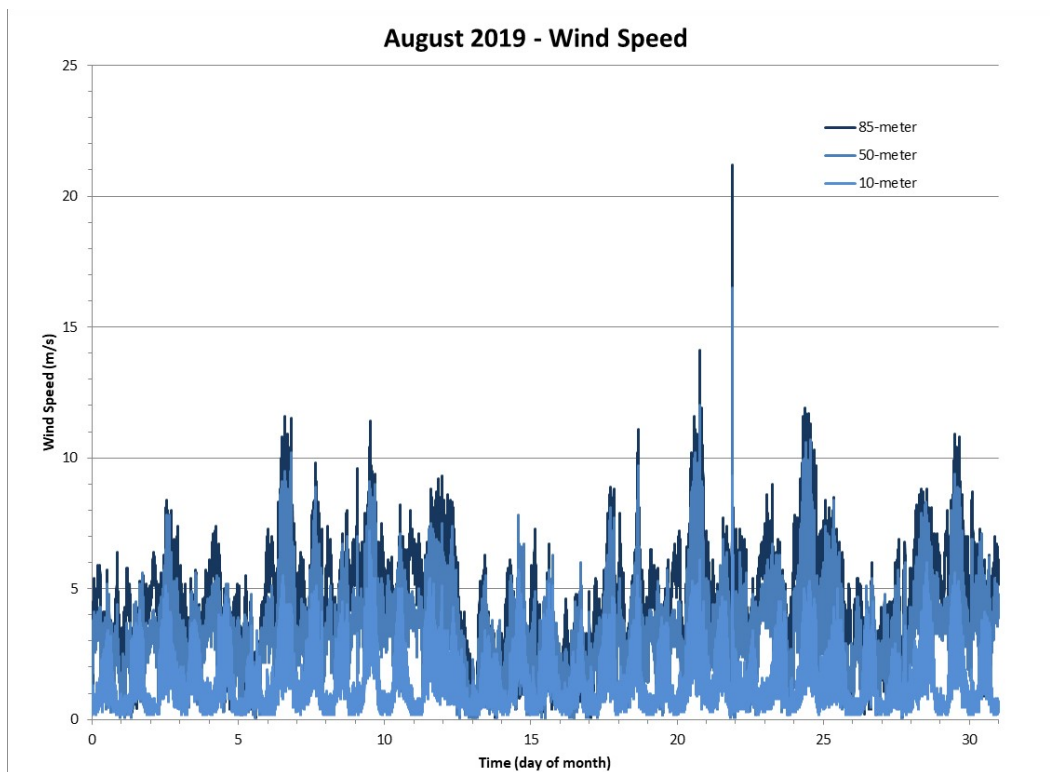


Figure 115 Wind Speed for the Month of August 2019

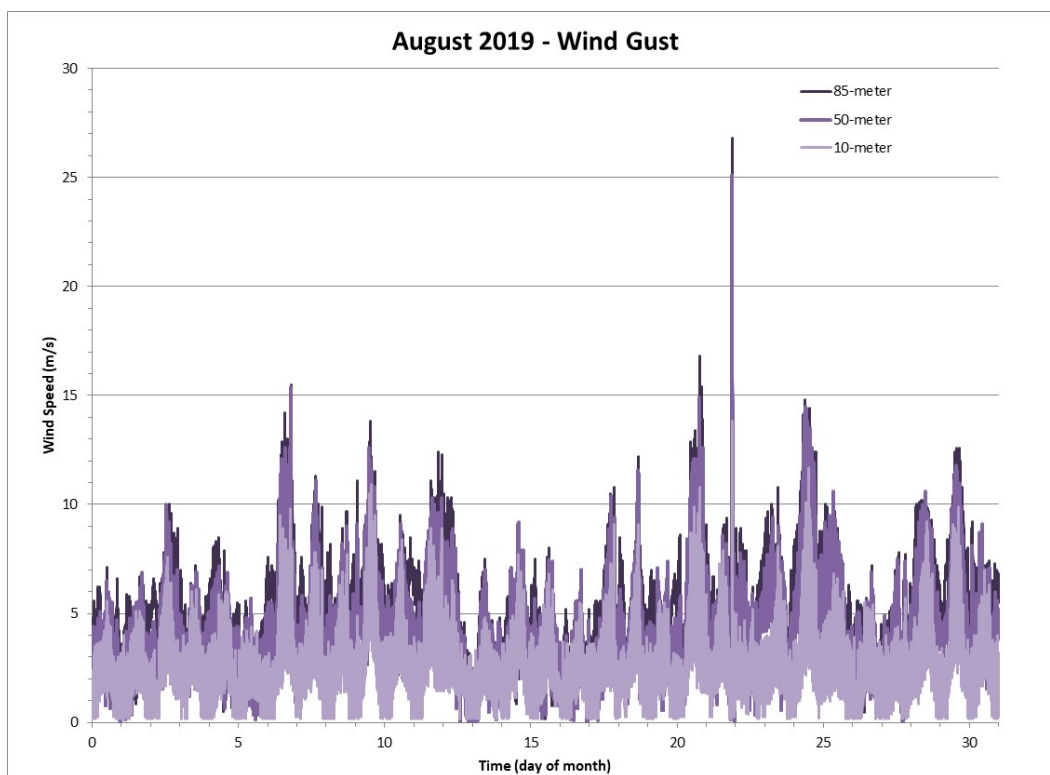


Figure 116 Wind Gust data for the Month of August 2019

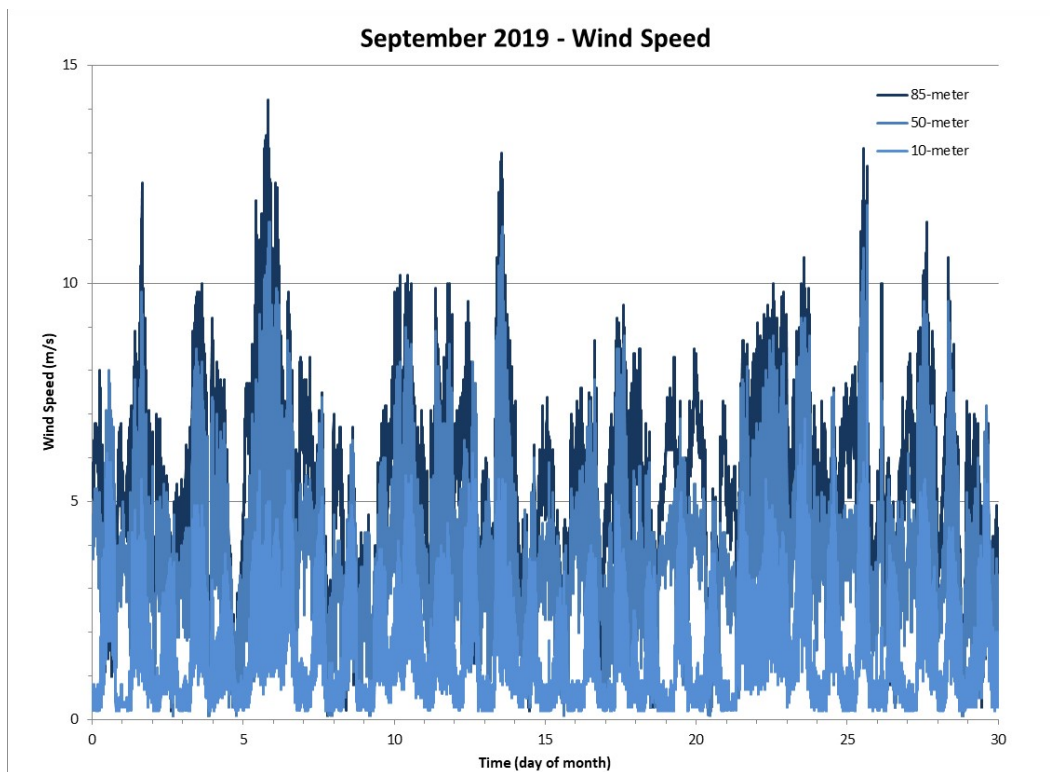


Figure 117 Wind Speed for the Month of September 2019

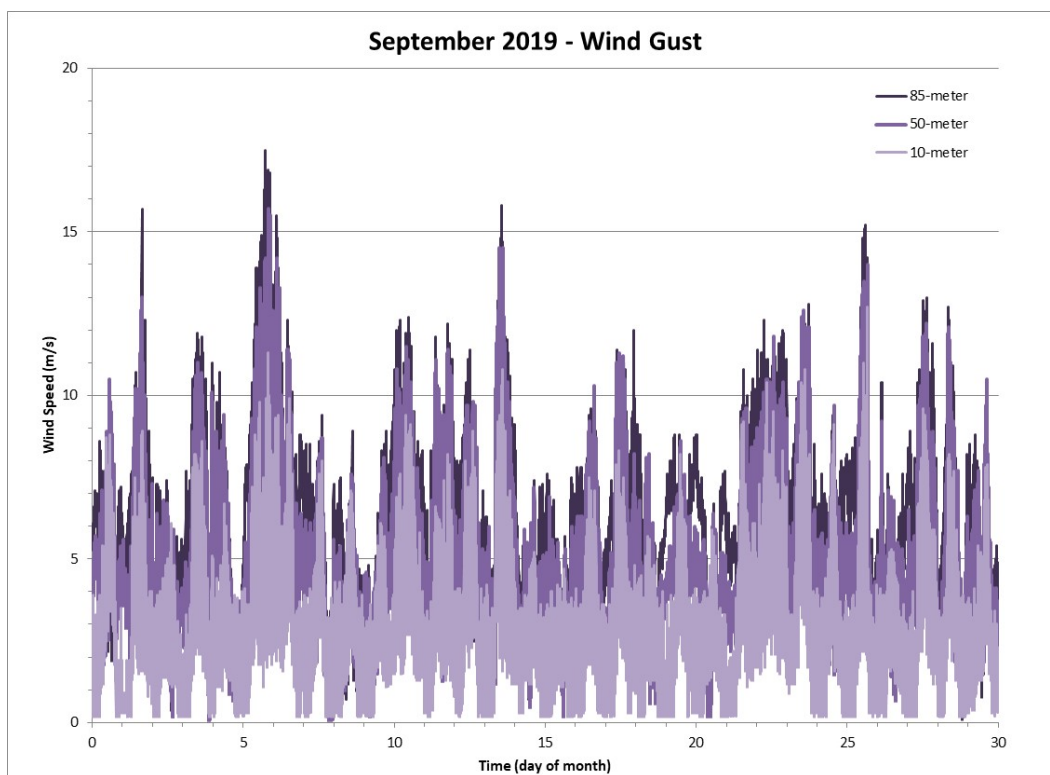


Figure 118 Wind Gust data for the Month of September 2019

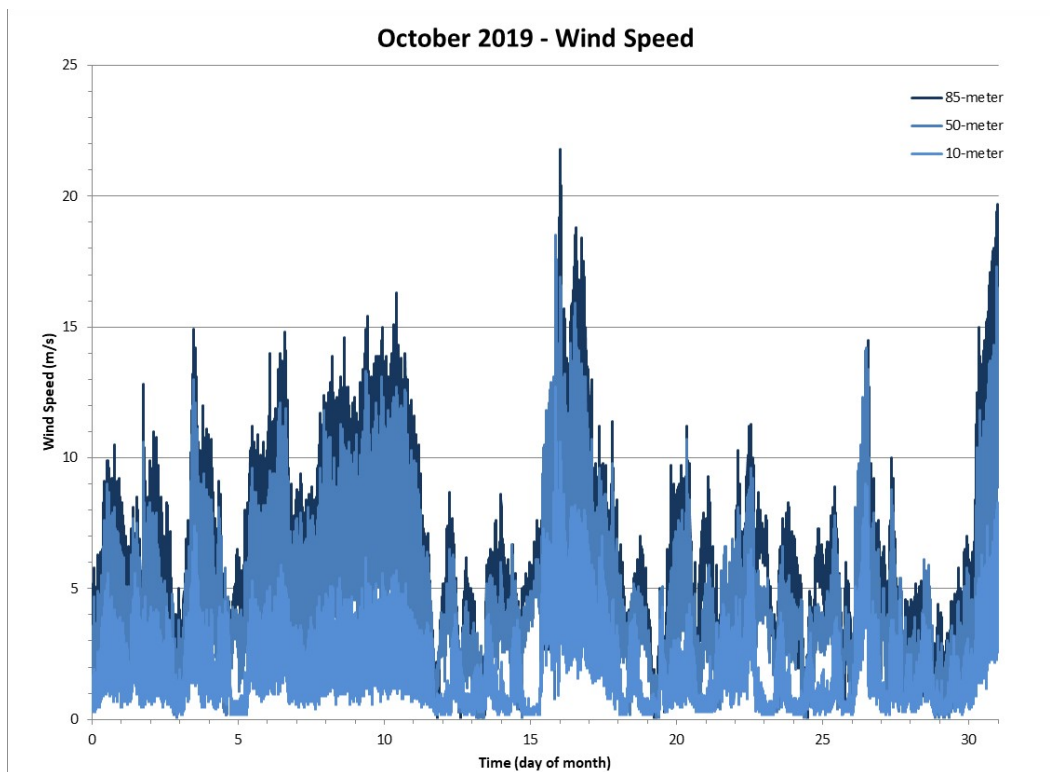


Figure 119 Wind Speed for the Month of October 2019

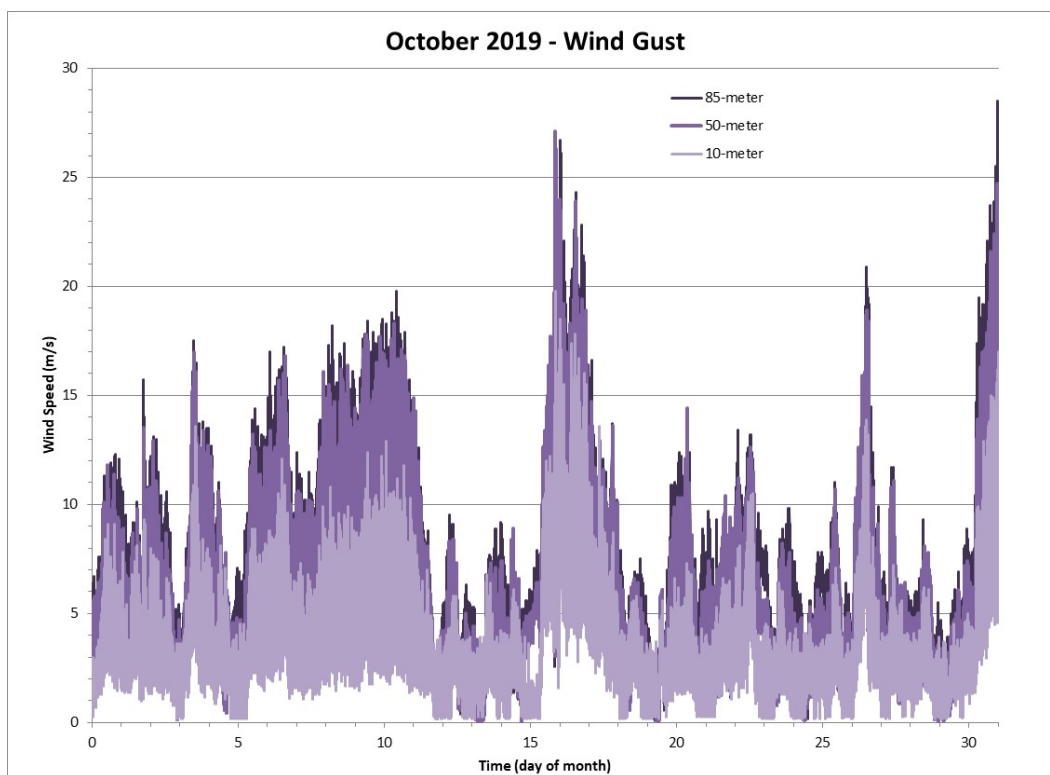


Figure 120 Wind Gust data for the Month of October 2019

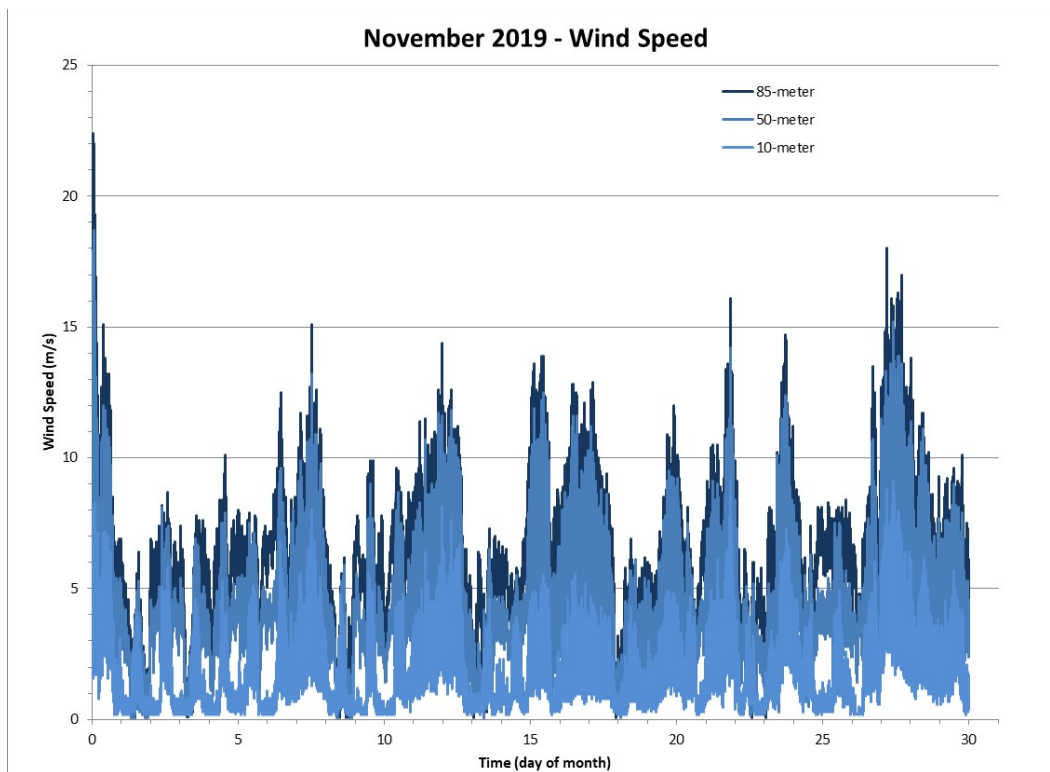


Figure 121 Wind Speed for the Month of November 2019

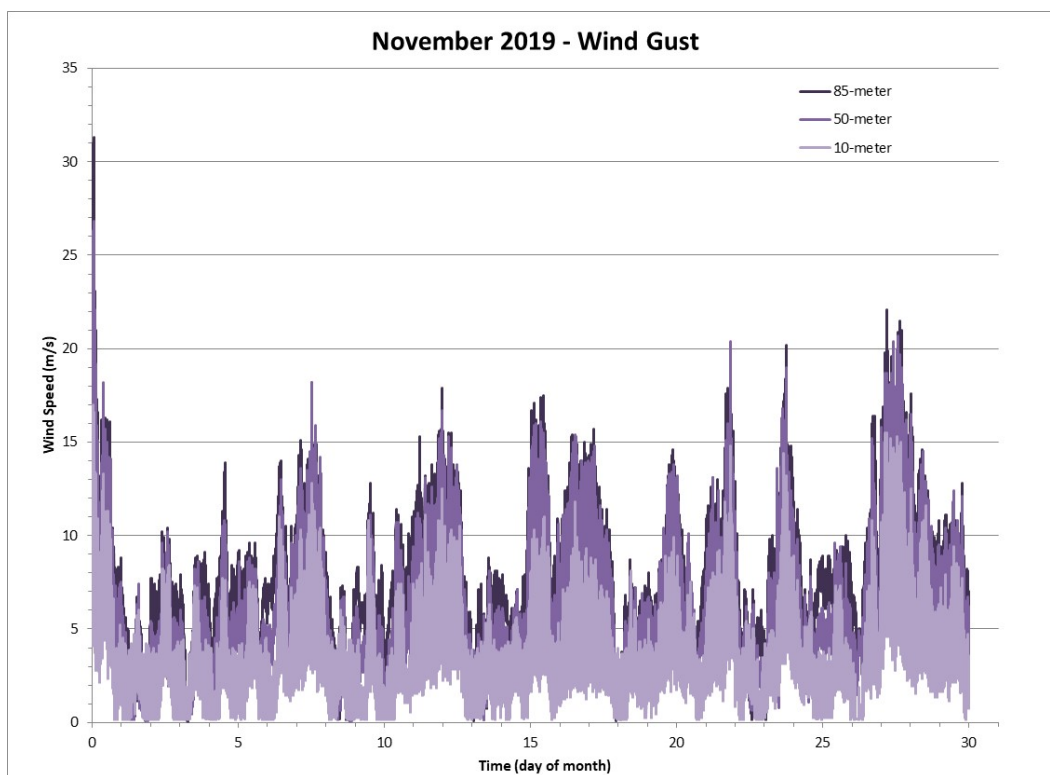


Figure 122 Wind Gust data for the Month of November 2019

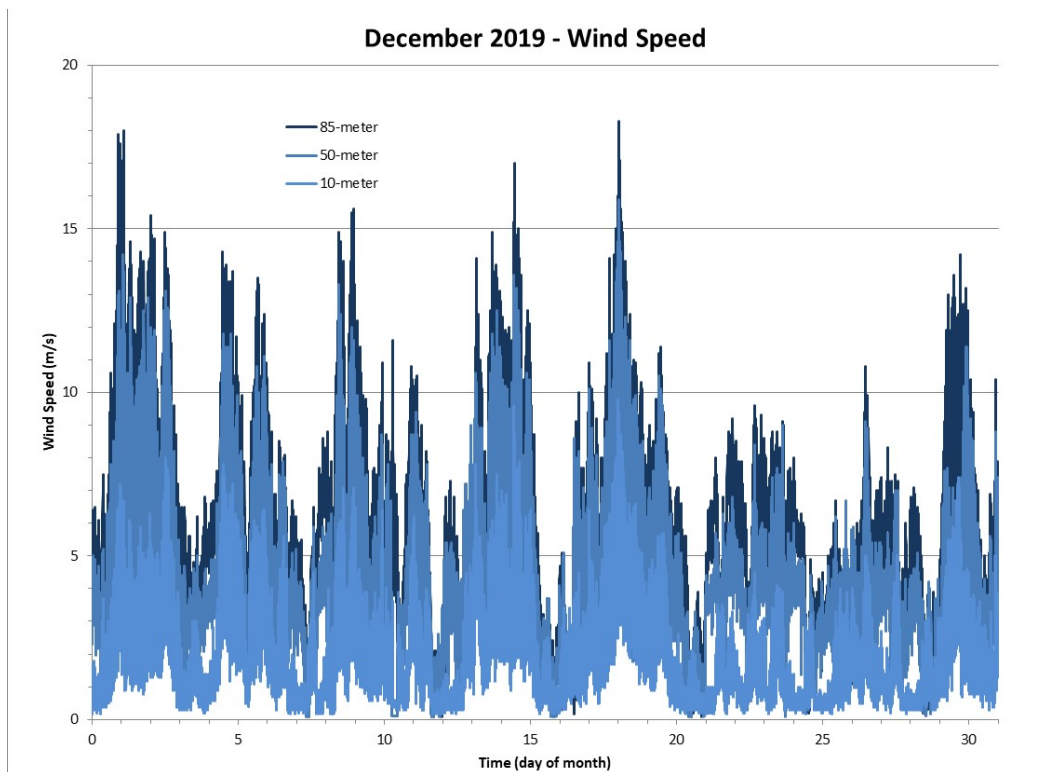


Figure 123 Wind Speed for the Month of December 2019

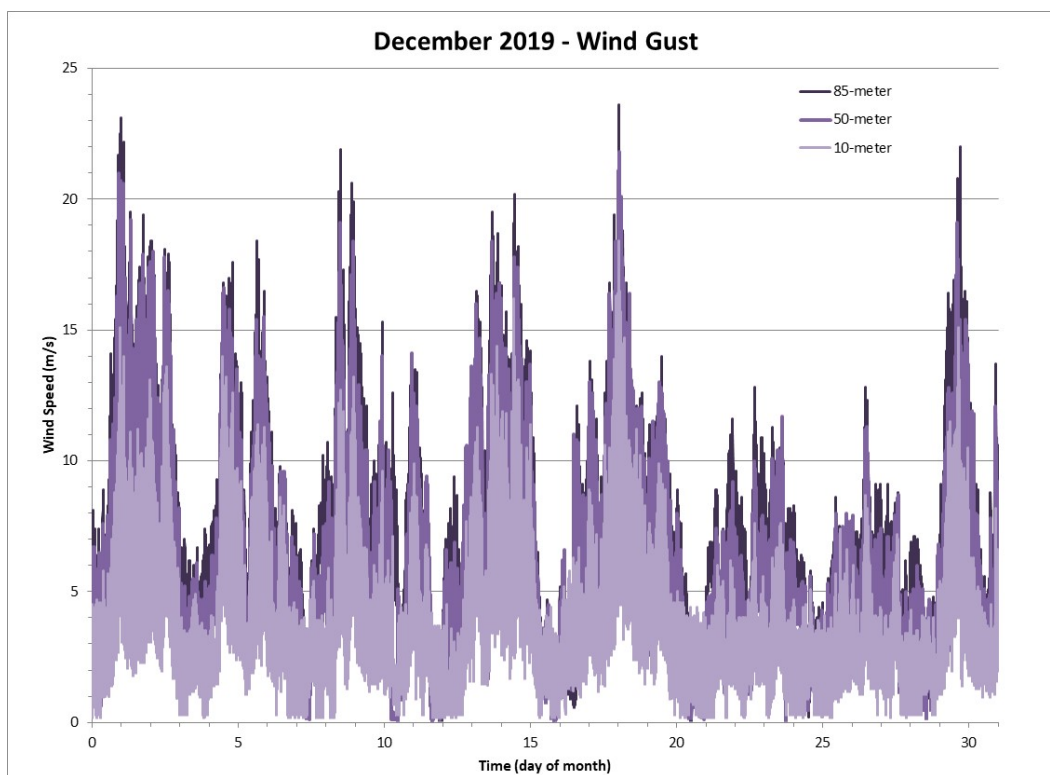


Figure 124 Wind Gust data for the Month of December 2019

## 2019 Solar Resource Data

Stability class determinations are required for environmental protection, Emergency response and environmental reporting (e.g., CAPP-88 for the USEPA). The best method to determine stability class is the SR-DT (solar radiation-delta temperature) method. To this end Met Services measures global horizontal irradiance. High quality solar resource data is also very important to research in the field of renewable energy. With BNL being home to the Long Island Solar Farm (LISF) and the Northeast Solar Energy Research Center (NSERC), it is important that BNL have a local source of dependable, quality assured data on solar radiation. As such BNL maintains a solar base station that records research grade one-minute data. This section reports solar incidence data including monthly data plots of the one-minute data.

### Global Solar Radiation

Global horizontal irradiance (GHI) is the total irradiance falling on a horizontal surface. It is defined by;

$$GHI = DHI + DNI \cdot \cos(\theta_z)$$

where; DHI = diffuse horizontal irradiance,

DNI = direct normal irradiance, and

$\theta_z$  = the solar zenith angle (incident angle of the beam)

Global short-wave radiation (near ultraviolet, visible & near-infrared) is measured using a Kipp & Zonen CMP-22 pyranometer attached to a powered ventilator and mounted on a SOLYS-2 sun tracker (Latitude 40° 52' 43" N, Longitude 72° 52' 26" W). This unit is sent off-site for calibration in the NREL BORCAL program. Currently, when the unit is out for calibration it is replaced with a calibrated CMP-21 pyranometer. The CMP-21 is a high precision research grade pyranometer that includes an integrated housing temperature sensor. The CMP-22 is also a high precision research grade pyranometer with a higher optical quality and higher refractive index quartz dome housing the sensor. Figures 131 through 142 present the monthly plots of global solar radiation.

Figure 125 presents the peak global solar irradiance at BNL for 2019. Figure 126 presents the average daily global solar irradiance at BNL for 2019. Figure 127 shows the monthly average daily irradiance for global and in-plane (angled to match the LISF panels). Table 8 gives the 2019 and historical monthly daily averages for global solar irradiance.

Table 8 Average Daily Solar Irradiance (Global) at BNL by Month (W/m<sup>2</sup>)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
1994	72	117	148	208	247	265	260	193	188	152	93	73	168
1995	75	108	183	232	282	168	97	301	290	151	86	77	171
1996	63	114	172	194	242	239	223	227	159	145	93	53	160

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
1997	80	119	152	227	261	284	289	225	180	145	78	71	176
1998	72	113	147	215	243	284	268	256	204	140	98	65	175
1999	74	114	195	223	250	285	270	224	219	156	97	78	182
2000	83	122	183	172	278	268	266	213	208	195	121	82	182
2001	82	125	148	221	289	282	284	228	203	159	106	75	183
2002	78	162	161	231	264	289	292	272	192	123	79	70	184
2003	84	74	174	192	190	263	250	295	175	119	80	59	163
2004	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan
2005	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan
2006	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan
2007	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan
2008	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan
2009	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan
2010	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan	nan
2011	86	121	178	173	224	254	277	224	130	130	98	75	164
2012	92	127	164	254	199	268	249	232	180	110	93	60	169
2013	83	110	163	244	237	257	239	210	190	129	96	61	168
2014	80	121	159	223	237	277	263	239	185	116	86	56	170
2015	80	119	161	211	262	233	252	250	200	137	88	57	171
2016	93	106	175	221	209	286	258	234	165	127	99	69	170
2017	64	120	160	186	217	254	239	219	171	128	85	63	159
2018	84	94	159	188	206	258	253	216	138	116	78	66	155
2019	77	112	173	181	219	247	277	221	194	109	90	57	163
<b>Average</b>	<b>82</b>	<b>114</b>	<b>166</b>	<b>209</b>	<b>223</b>	<b>259</b>	<b>256</b>	<b>227</b>	<b>172</b>	<b>122</b>	<b>90</b>	<b>63</b>	<b>165</b>
Max	93	127	178	254	262	286	277	250	200	137	99	75	171
Min	64	94	159	173	199	233	239	210	130	109	78	56	155

nan indicates missing data, Values in fields filled in yellow are the monthly averages inserted because of partially missing data, the average then changes with addition of this value. Statistics are based on 2011 to present.

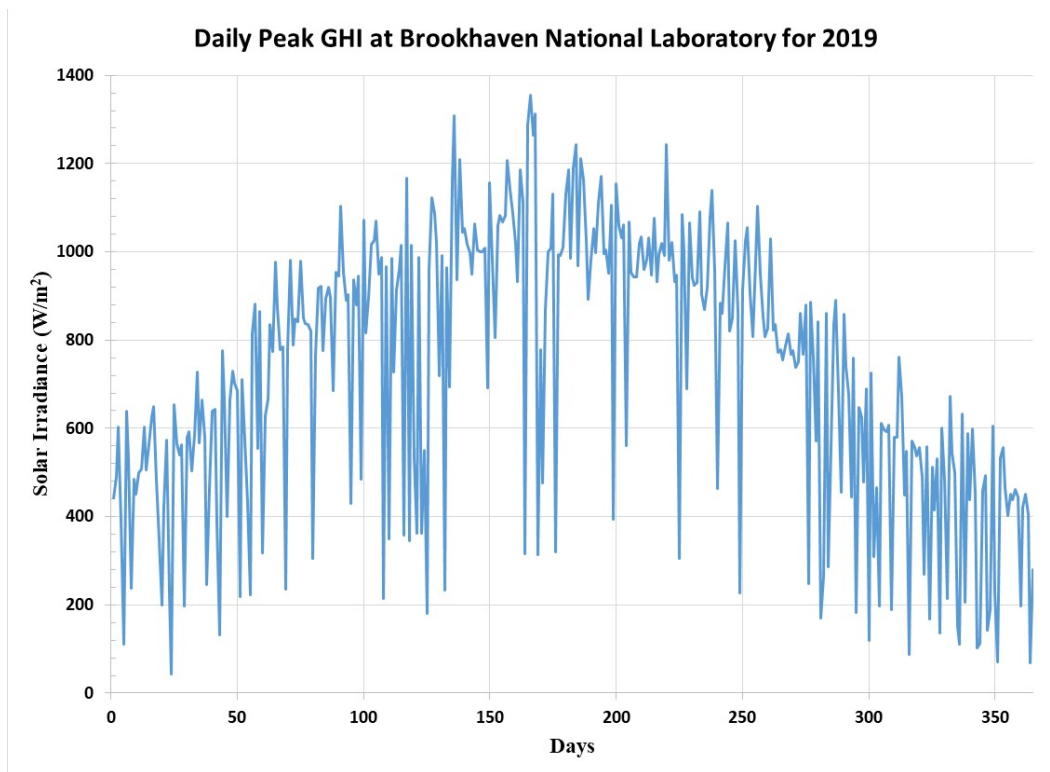


Figure 125 Daily Peak Solar Irradiance at Brookhaven National Laboratory for 2019

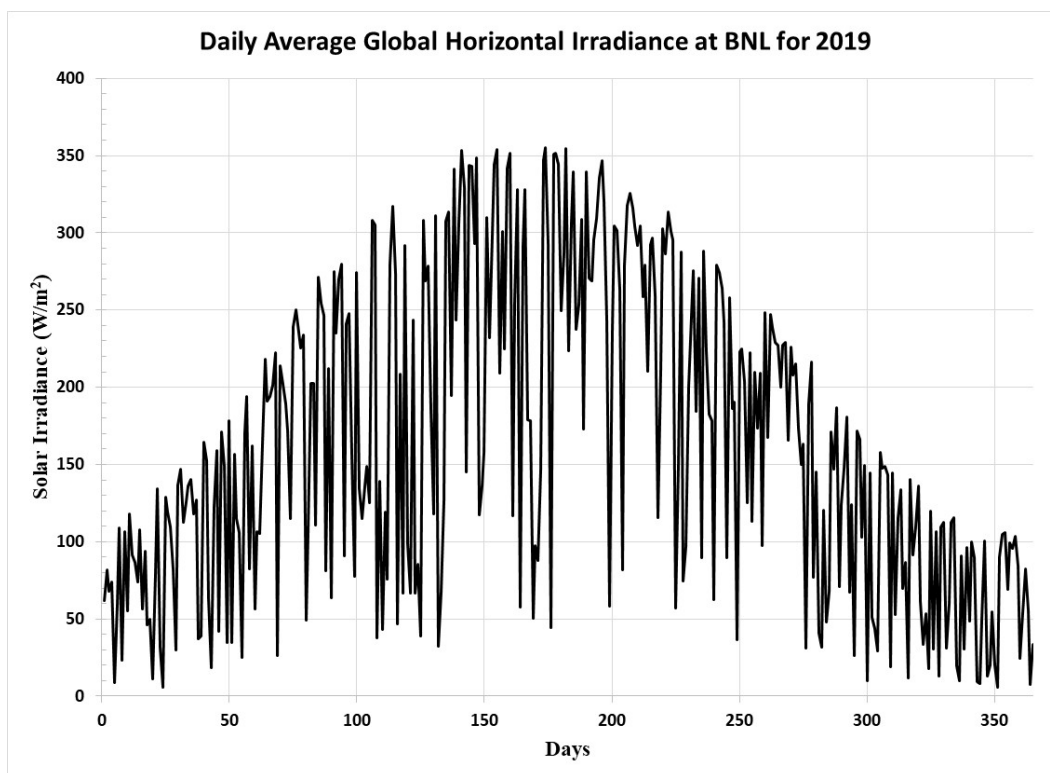


Figure 126 Average Daily Solar Irradiance at Brookhaven National Laboratory for 2019

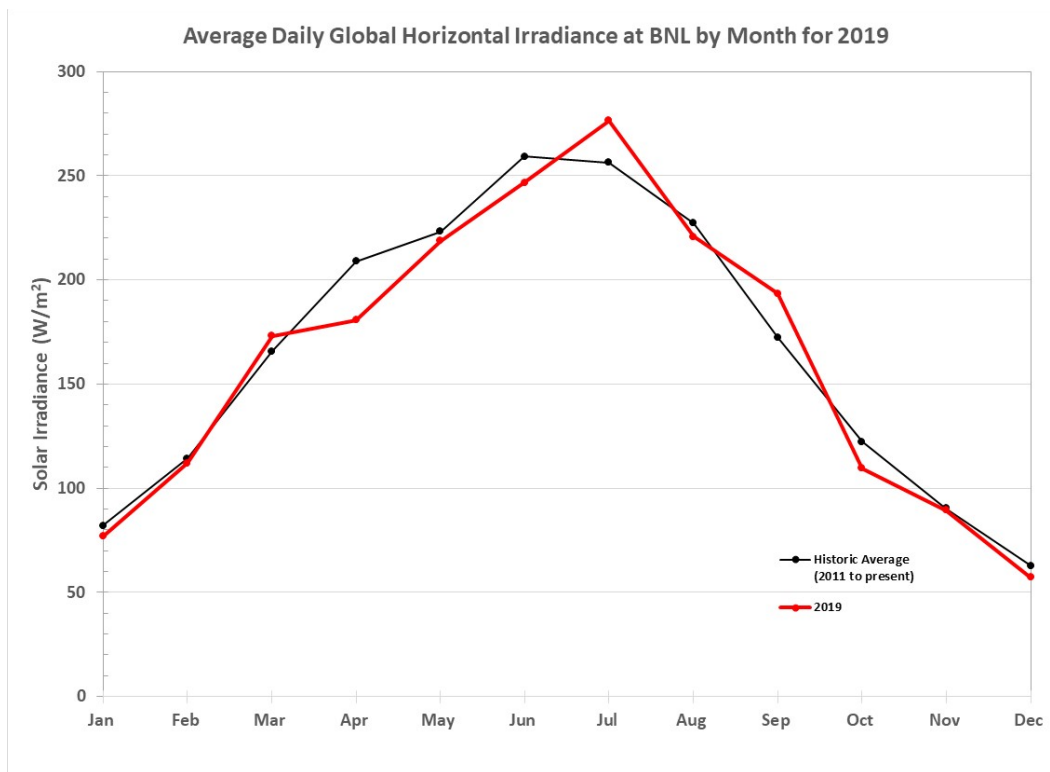


Figure 127 Global Horizontal Irradiance – 2019 Monthly Daily-Average

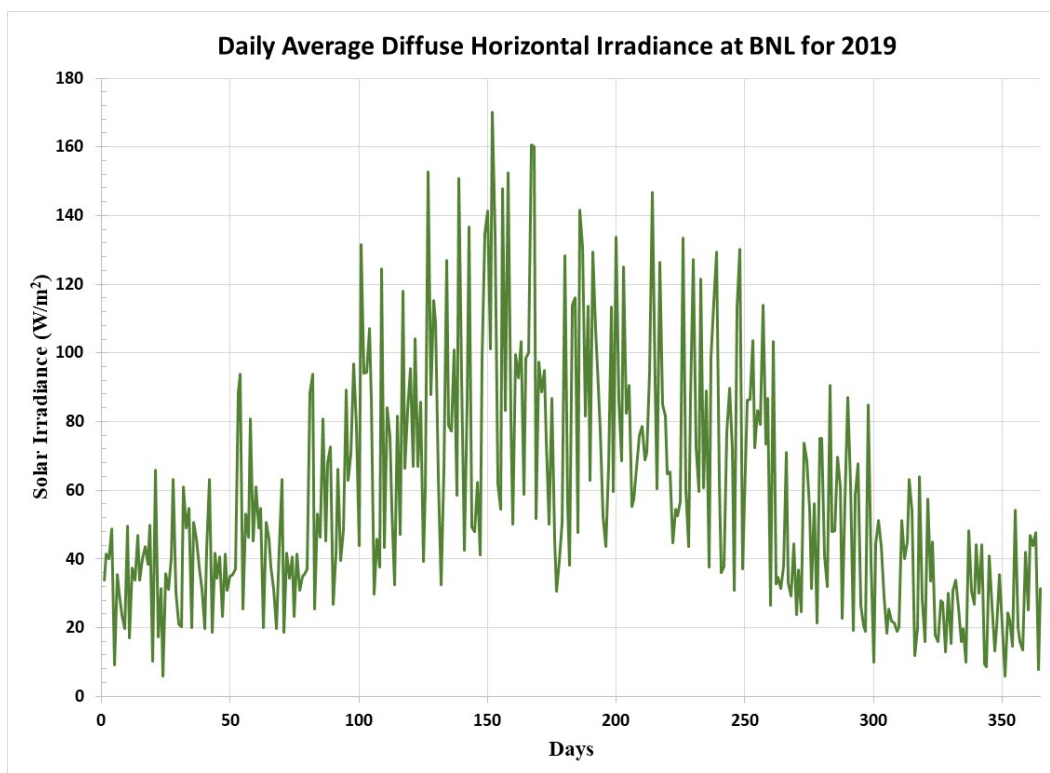


Figure 128 Average Daily Diffuse Solar Irradiance at Brookhaven National Laboratory for 2019

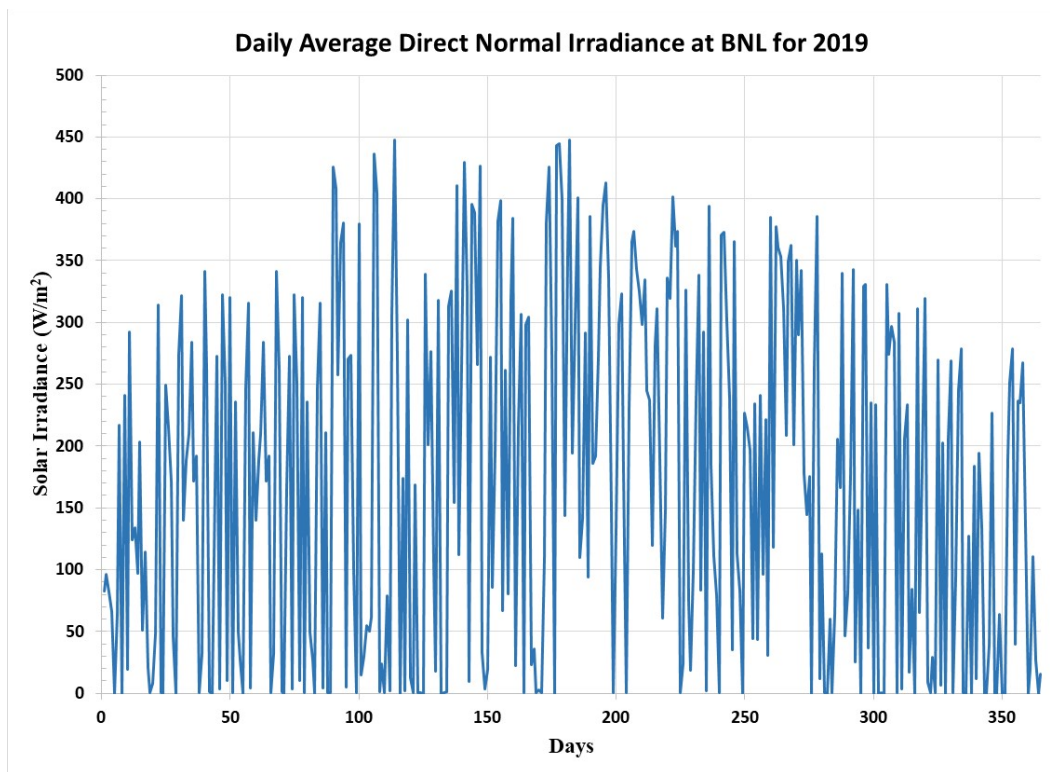


Figure 129 Average Daily Direct Normal Solar Irradiance at Brookhaven National Laboratory for 2019

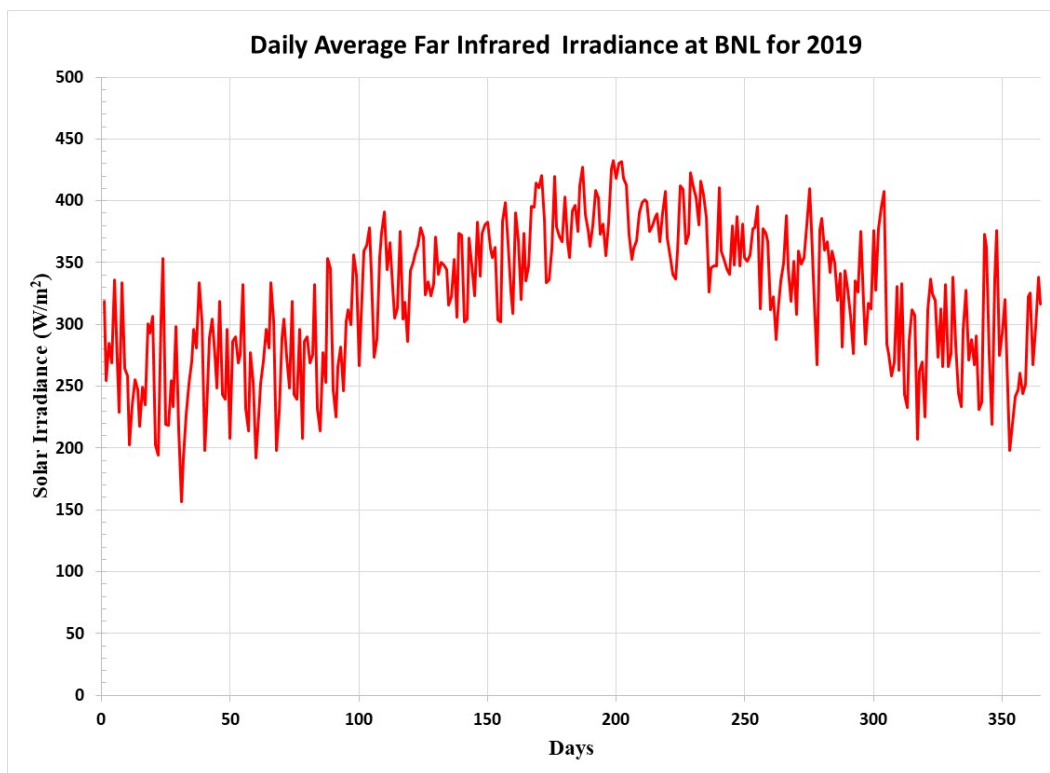


Figure 130 Average Daily Long-wave Far Infrared Irradiance at Brookhaven National Laboratory for 2019

## **Diffuse Solar Radiation**

Diffuse solar irradiance is the radiation that is scattered (i.e., by clouds and dust particles) as it passes through the atmosphere. Diffuse short-wave radiation (ultraviolet, visible & near-infrared) is measured using a shaded Kipp & Zonen CMP-22 pyranometer with a powered ventilator mounted on a SOLYS-2 sun tracker. This unit is sent off-site for calibration in the NREL BORCAL program. Currently, when the unit is out for calibration it is replaced with a calibrated CMP-21 pyranometer. Figure 128 gives the average daily diffuse irradiance for the year. Figures 143 through 154 present the monthly plots of diffuse solar radiation.

## **Direct Solar Radiation**

Direct normal irradiance (DNI) is the solar radiation that travels in a straight path to a detector that is perpendicular to the light path. The direct short-wave radiation is measured with a Kipp & Zonen CHP-1 pyrliometer attached to a SOLYS-2 sun tracker. The CHP-1 is a thermopile that absorbs 97-98% of the total incident radiation. The reported maximum uncertainty is 2% for hourly measurements and 1% for daily totals. Figure 129 gives the average daily direct normal irradiance for the year. Figures 155 through 166 present the monthly plots of direct solar radiation.

## **Long-wave Far Infrared Radiation**

Downward long-wave far infrared radiation is measured using a shaded Kipp & Zonen CGR-4 pyrgeometer with a powered ventilator mounted on the SOLYS-2 sun tracker. The CGR-4 is a research grade thermopile. This unit is sent off-site for calibration in the NREL BORCAL program. A duplicate unit is stocked which is sent to NREL for calibration and replaces the in service unit when returned. The CGR-4 has a built in temperature sensor and temperature correction is applied. The reported maximum daily uncertainty is 3%. Figure 130 gives the average daily long-wave infrared irradiance. Figures 167 through 178 present the monthly plots of long-wave infrared irradiance.

## **LISF and NSERC Reference Pyranometers**

The Long Island Solar Farm (LISF) and NorthEast Solar Research Center (NSERC) both have a network of pyranometers and meteorological sensors to provide data for solar research. Each of the 25 LISF powerblocks and the three areas of NSERC has a pair of Kipp & Zonen pyranometers that measure global and tilted global solar radiation. As a reference for the LISF sensor array, two Kipp and Zonen model SP-lite2 pyranometers are maintained at the base station on building 490D, one in-plane (tilted global radiation) at the 27° angle of inclination used for the panels at the LISF and one horizontal (global radiation). A corresponding set of SP-

lite2 pyranometers are maintained for the NSERC with the in-plane at an angle of  $23^\circ$ . The horizontal (global) solar radiation plots, as measured via SP-lite2 pyranometers, are presented in Figures 179 through 190. The in-plane or tilted global radiation for both LISF and NSERC is presented in Figures 191 through 214.

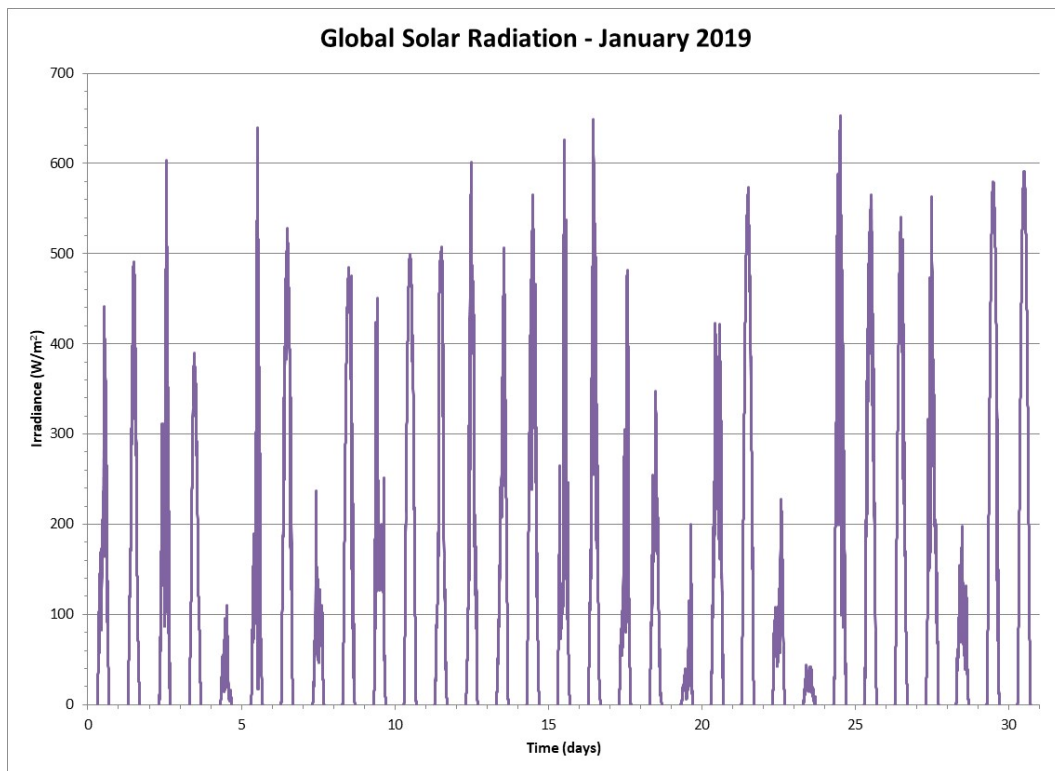


Figure 131 Global Solar Radiation for the Month of January 2019

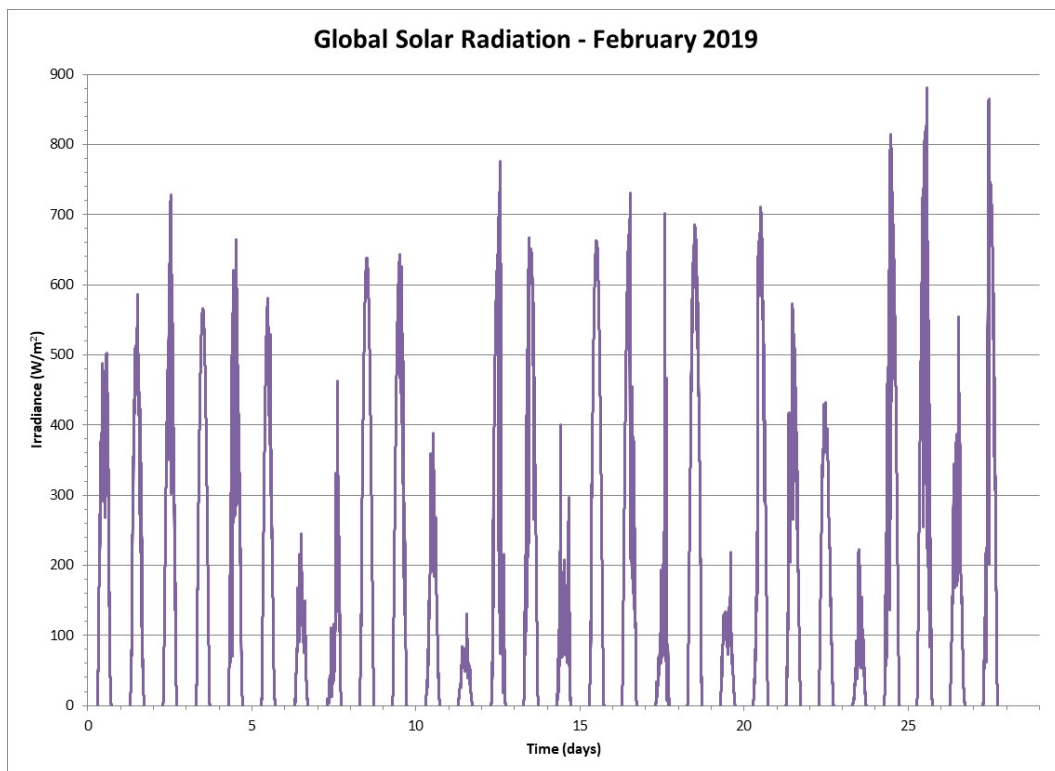


Figure 132 Global Solar Radiation for the Month of February 2019

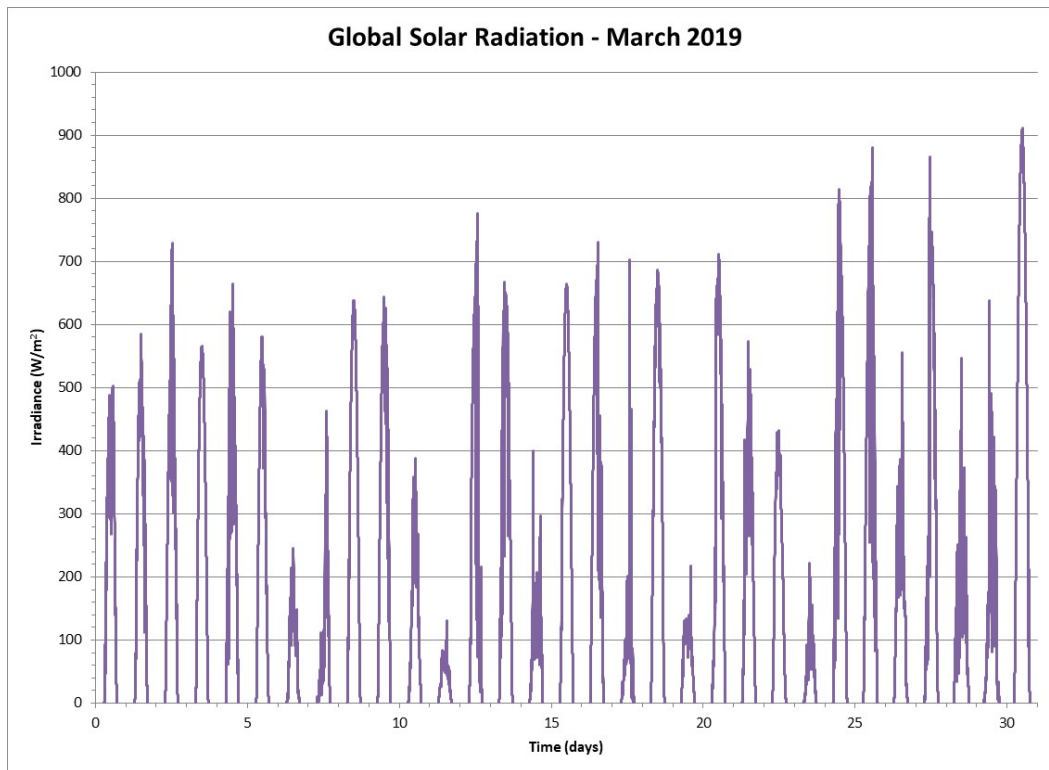


Figure 133 Global Solar Radiation for the Month of March 2019

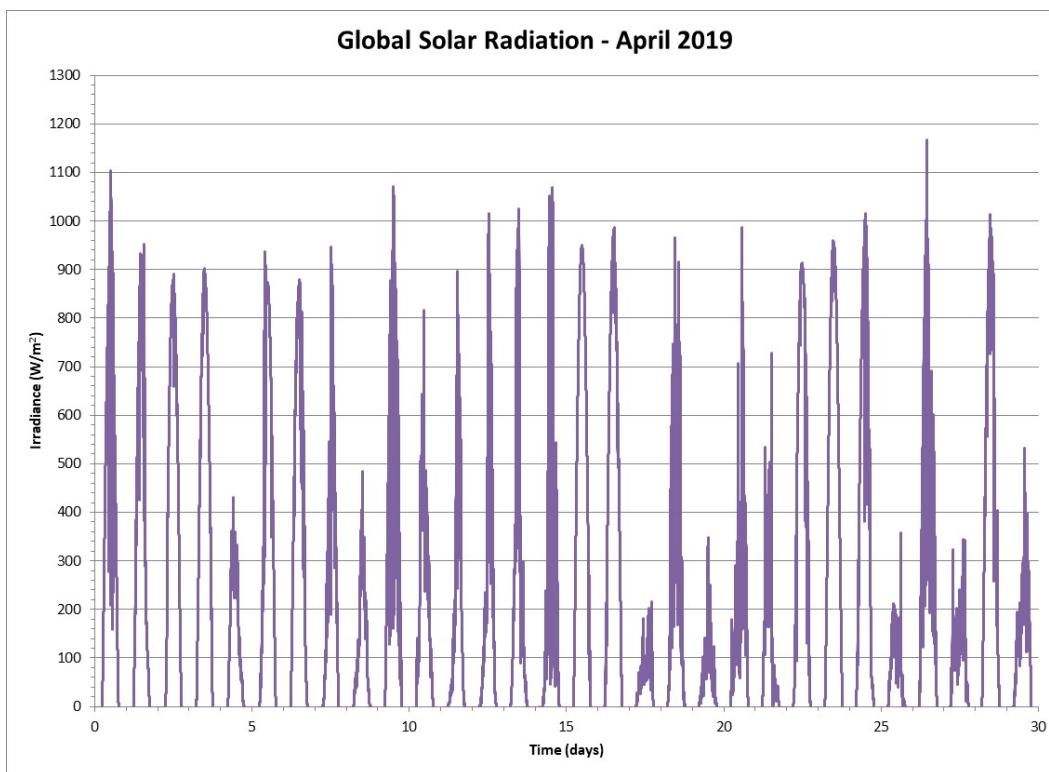


Figure 134 Global Solar Radiation for the Month of April 2019

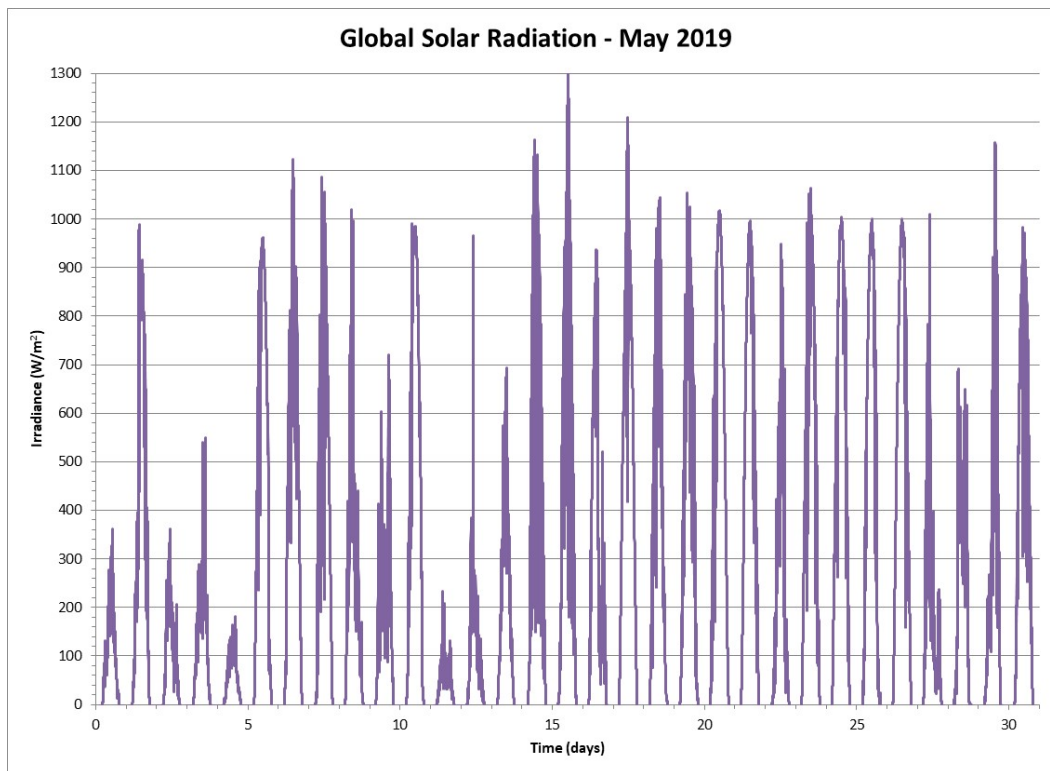


Figure 135 Global Solar Radiation for the Month of May 2019

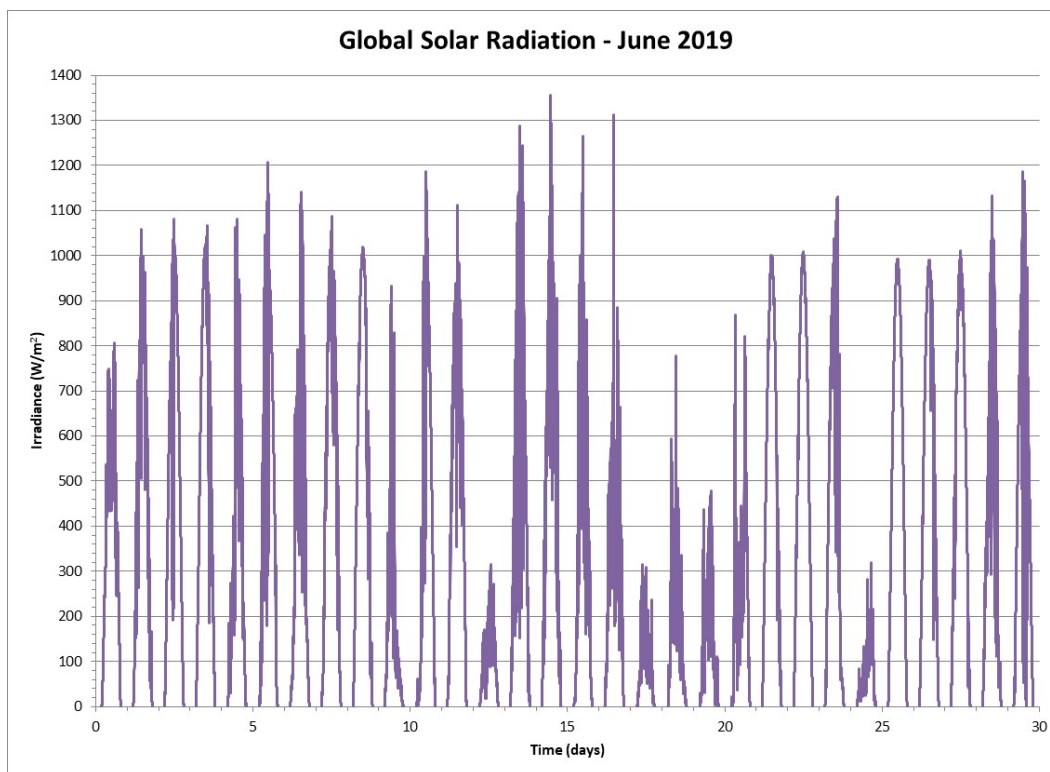


Figure 136 Global Solar Radiation for the Month of June 2019

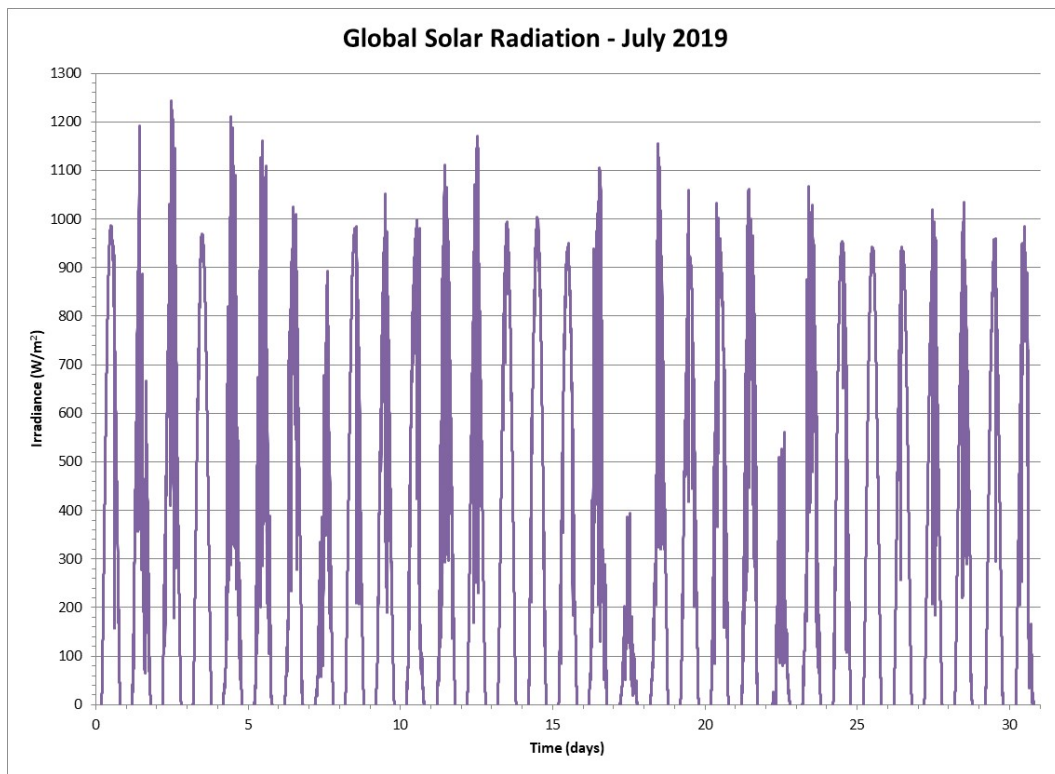


Figure 137 Global Solar Radiation for the Month of July 2019

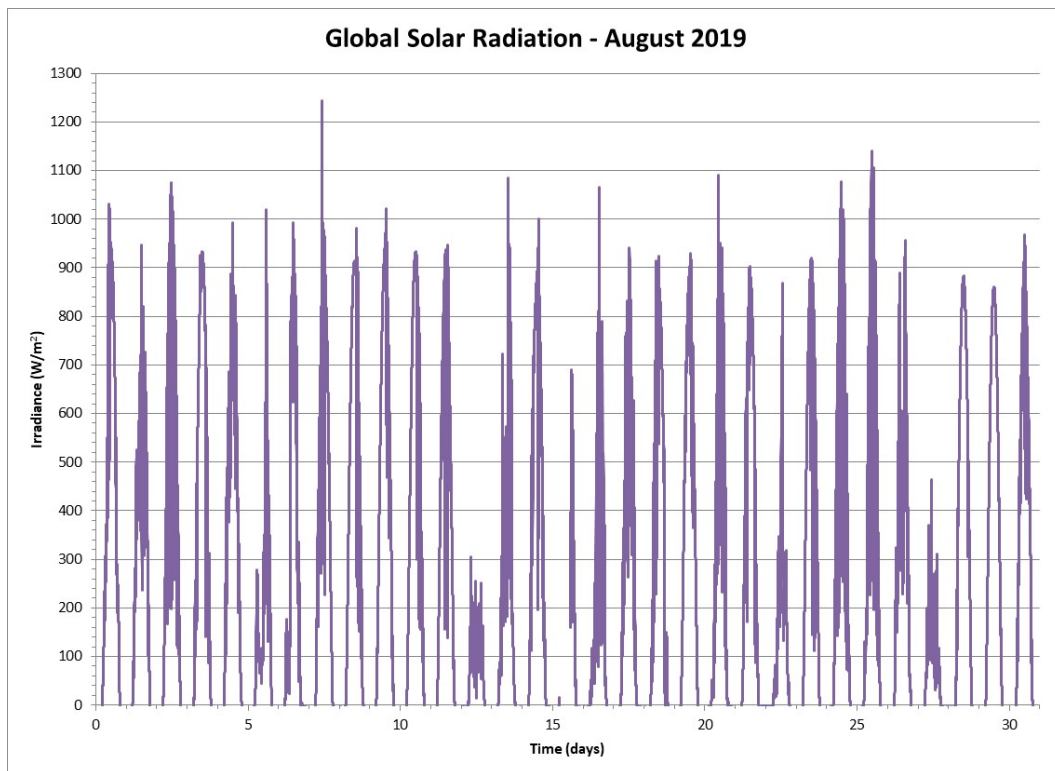


Figure 138 Global Solar Radiation for the Month of August 2019

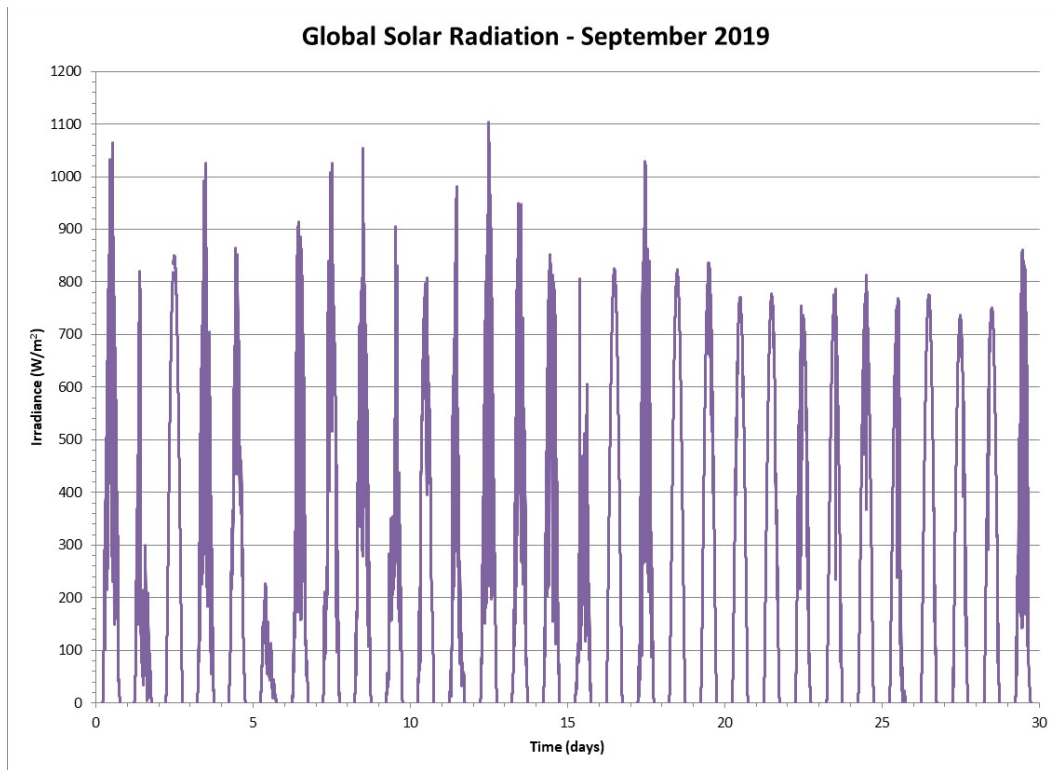


Figure 139 Global Solar Radiation for the Month of September 2019

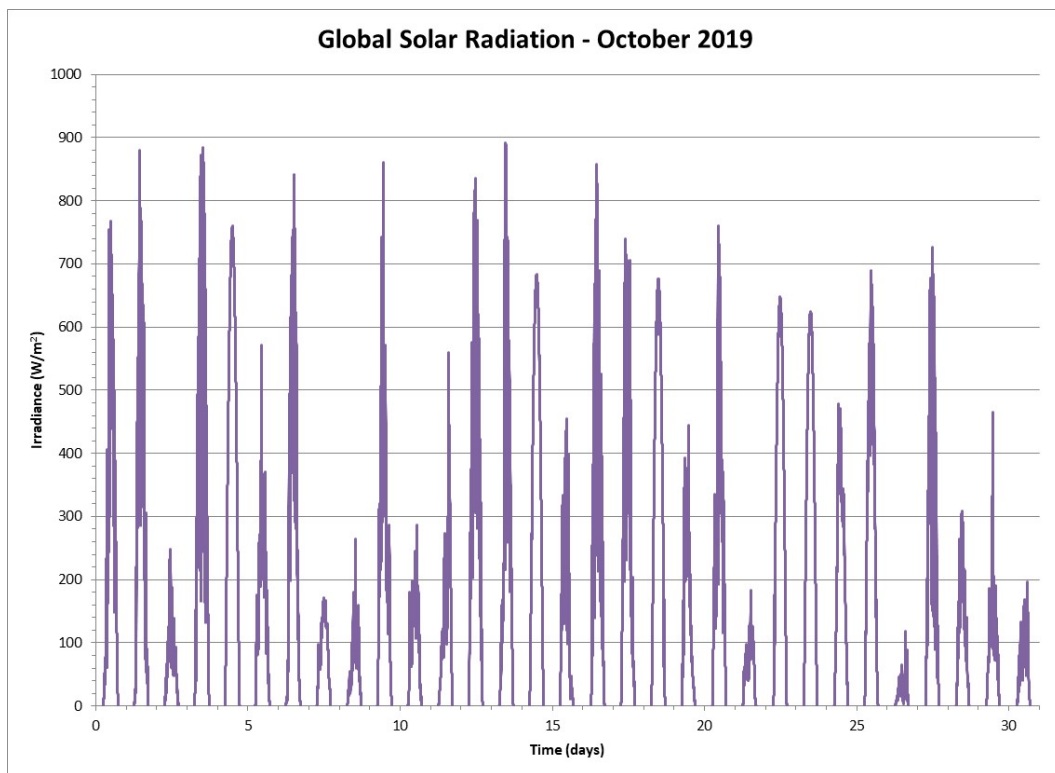


Figure 140 Global Solar Radiation for the Month of October 2019

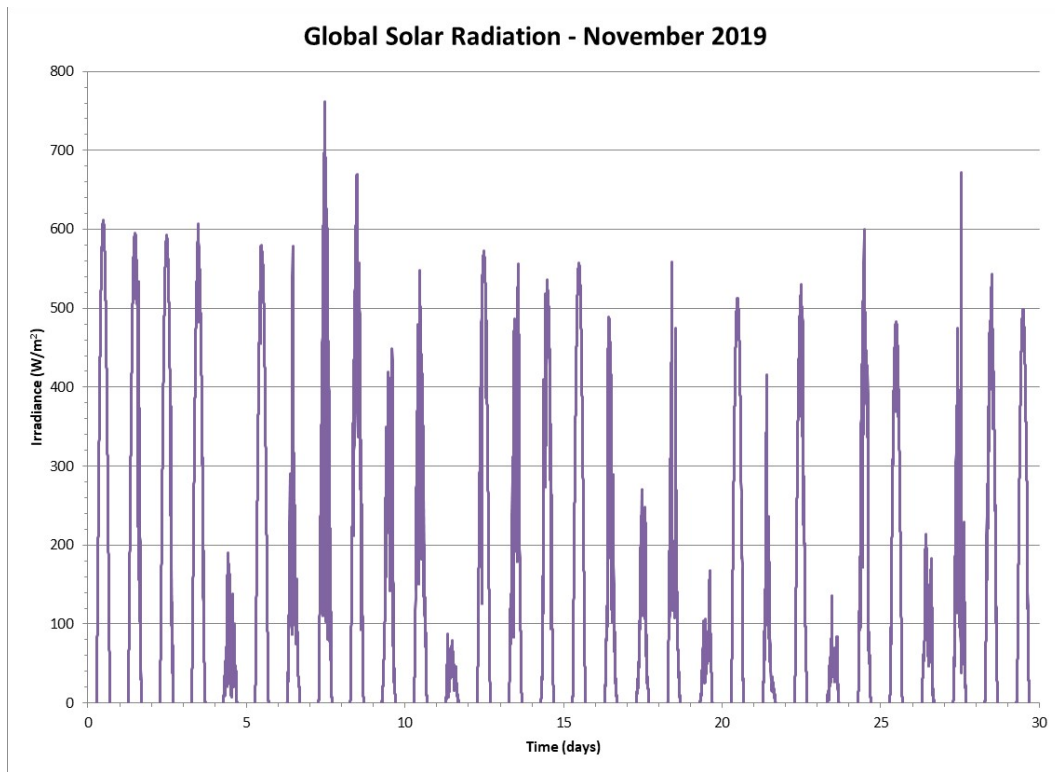


Figure 141 Global Solar Radiation for the Month of November 2019

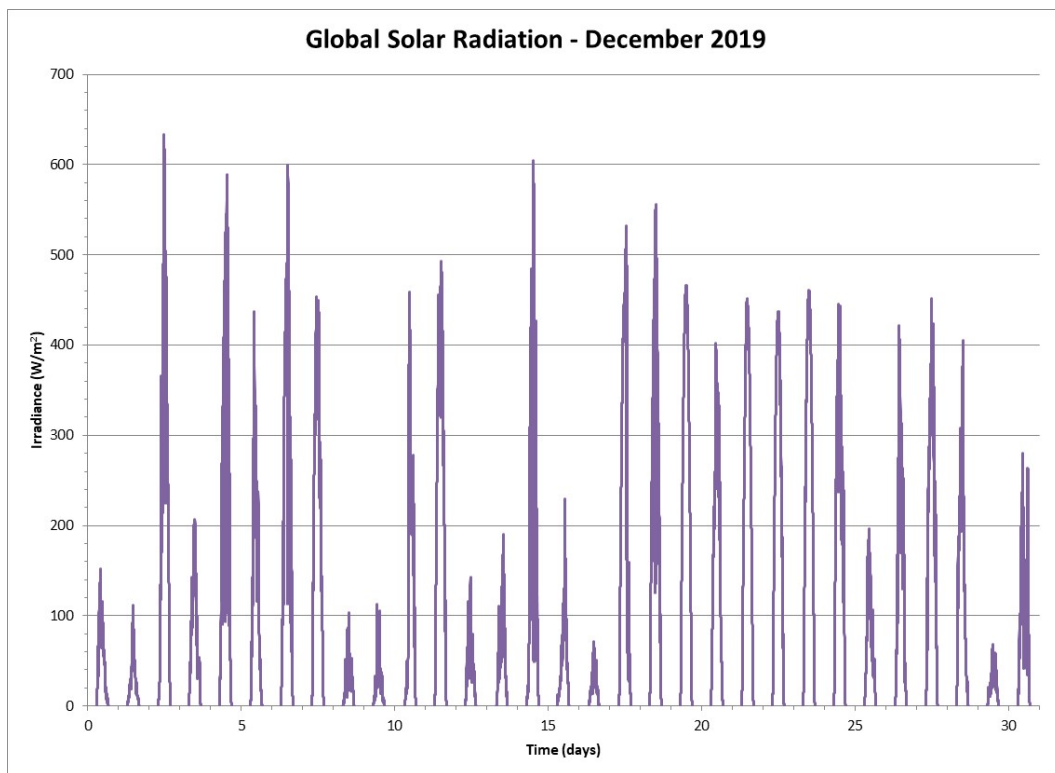


Figure 142 Global Solar Radiation for the Month of December 2019

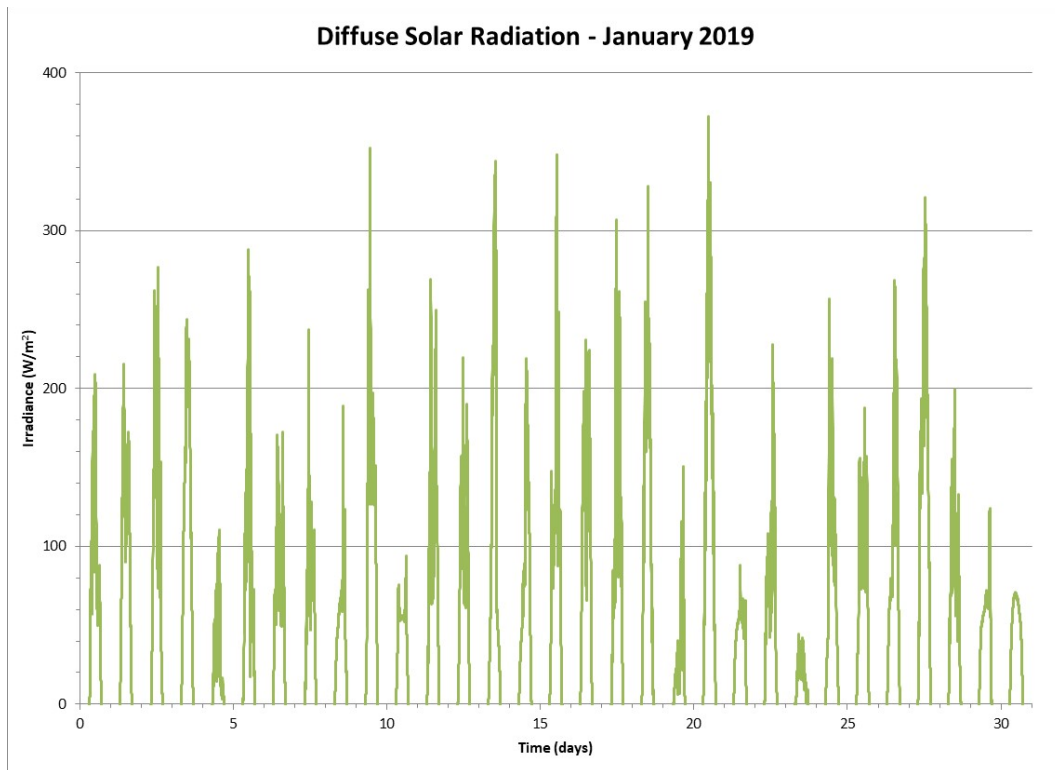


Figure 143 Diffuse Solar Radiation for the Month of January 2019

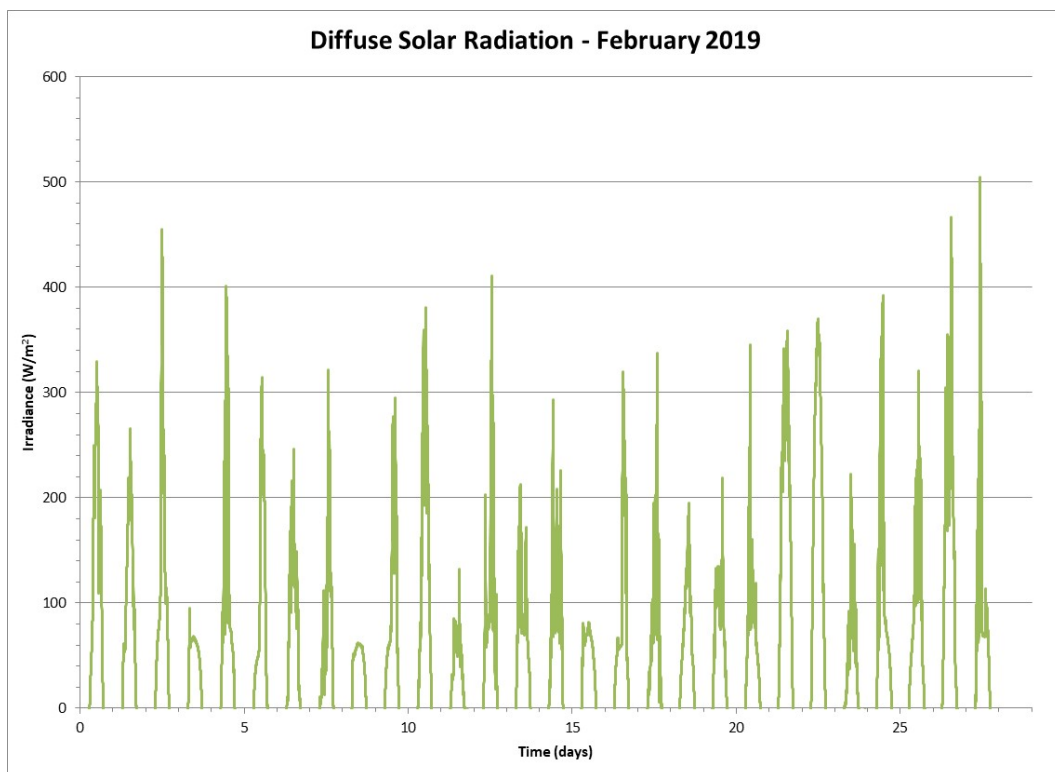


Figure 144 Diffuse Solar Radiation for the Month of February 2019

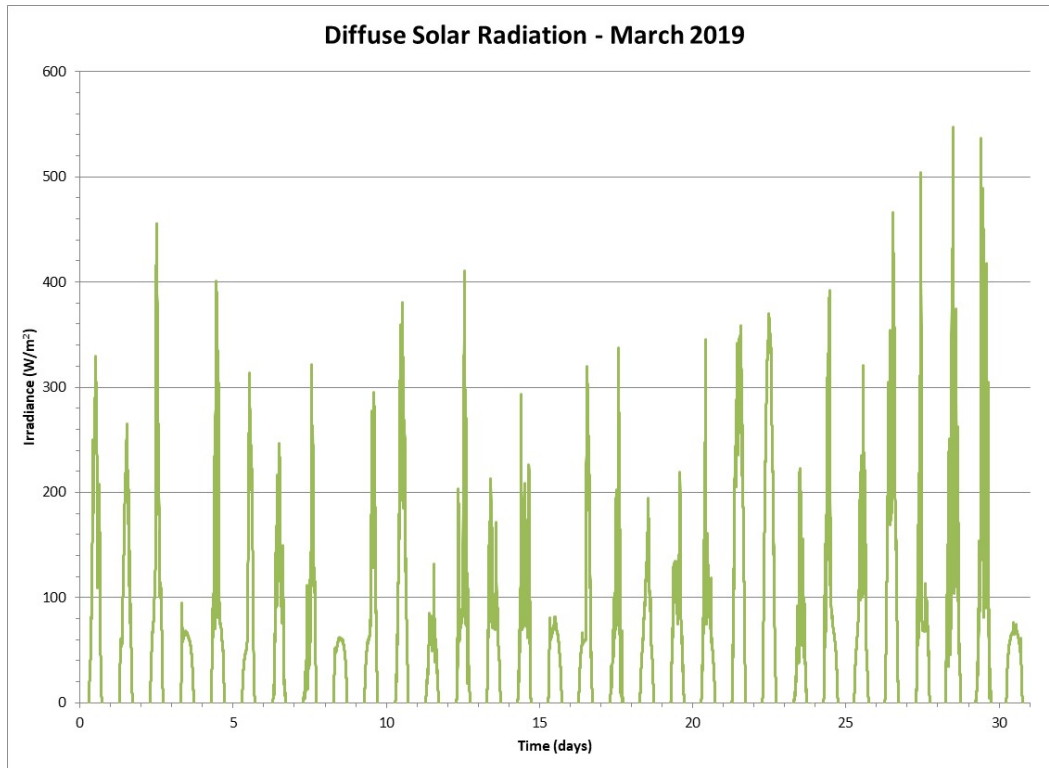


Figure 145 Diffuse Solar Radiation for the Month of March 2019

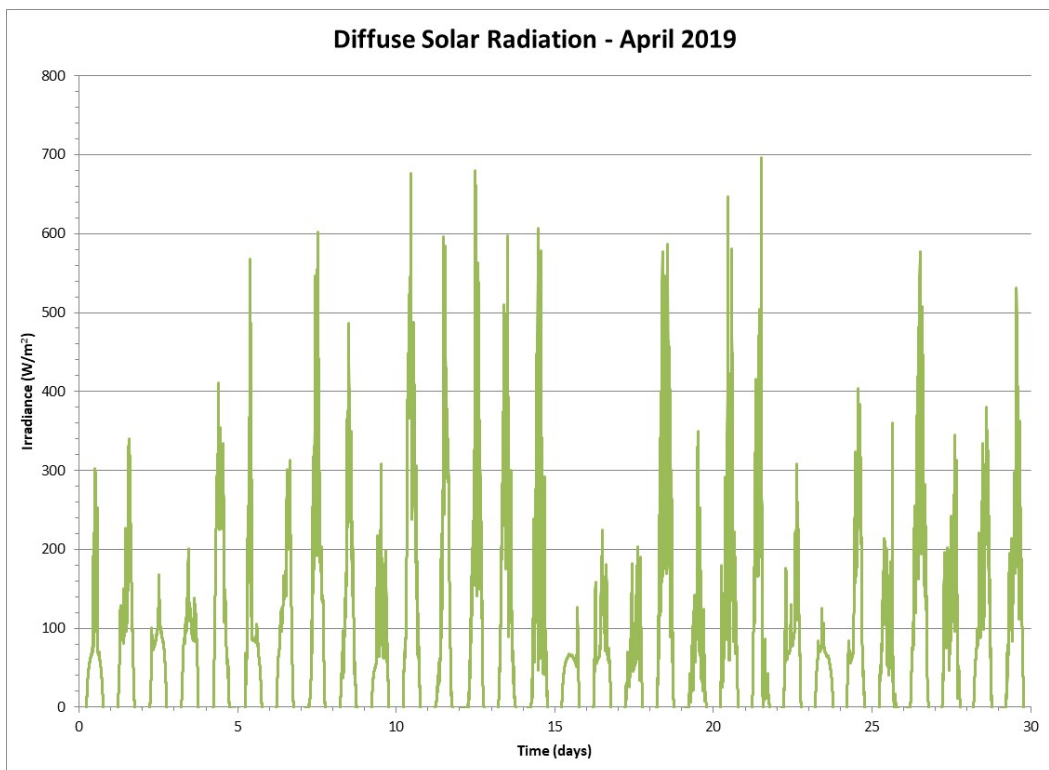


Figure 146 Diffuse Solar Radiation for the Month of April 2019

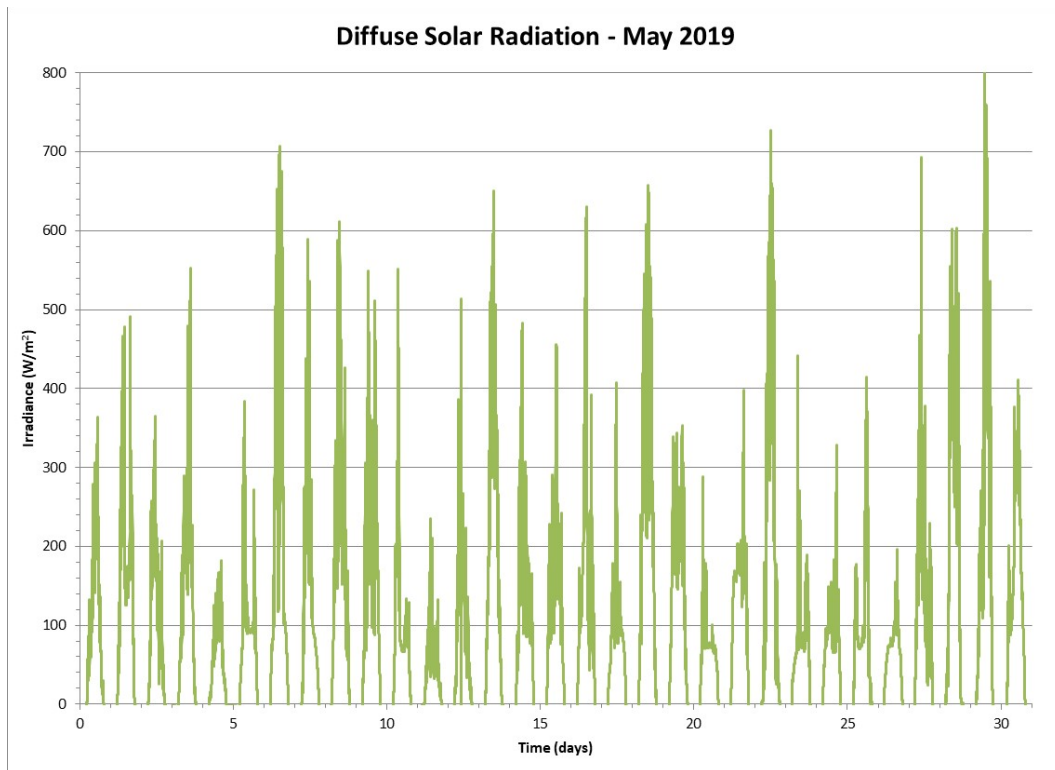


Figure 147 Diffuse Solar Radiation for the Month of May 2019

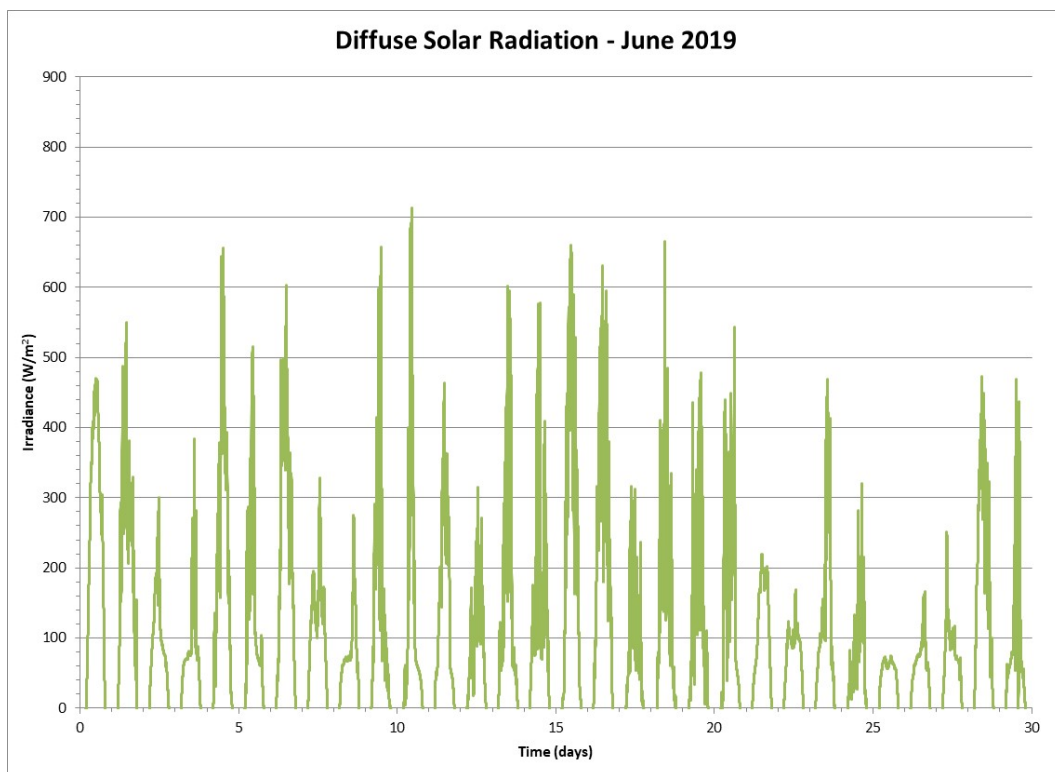


Figure 148 Diffuse Solar Radiation for the Month of June 2019

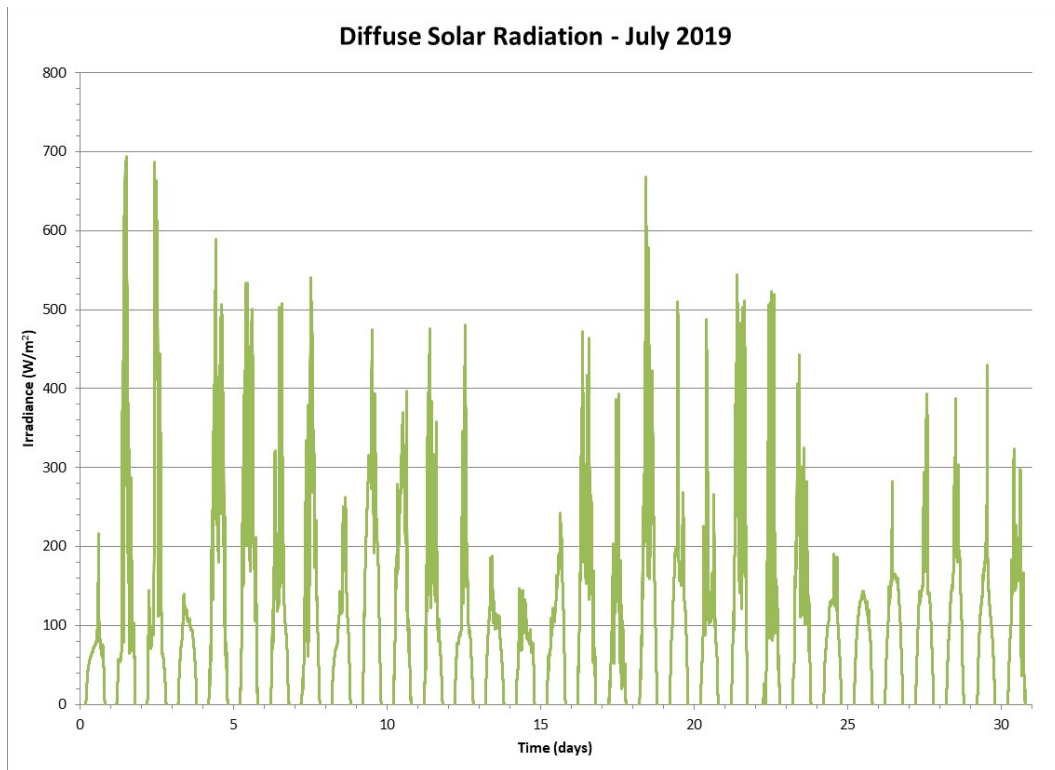


Figure 149 Diffuse Solar Radiation for the Month of July 2019

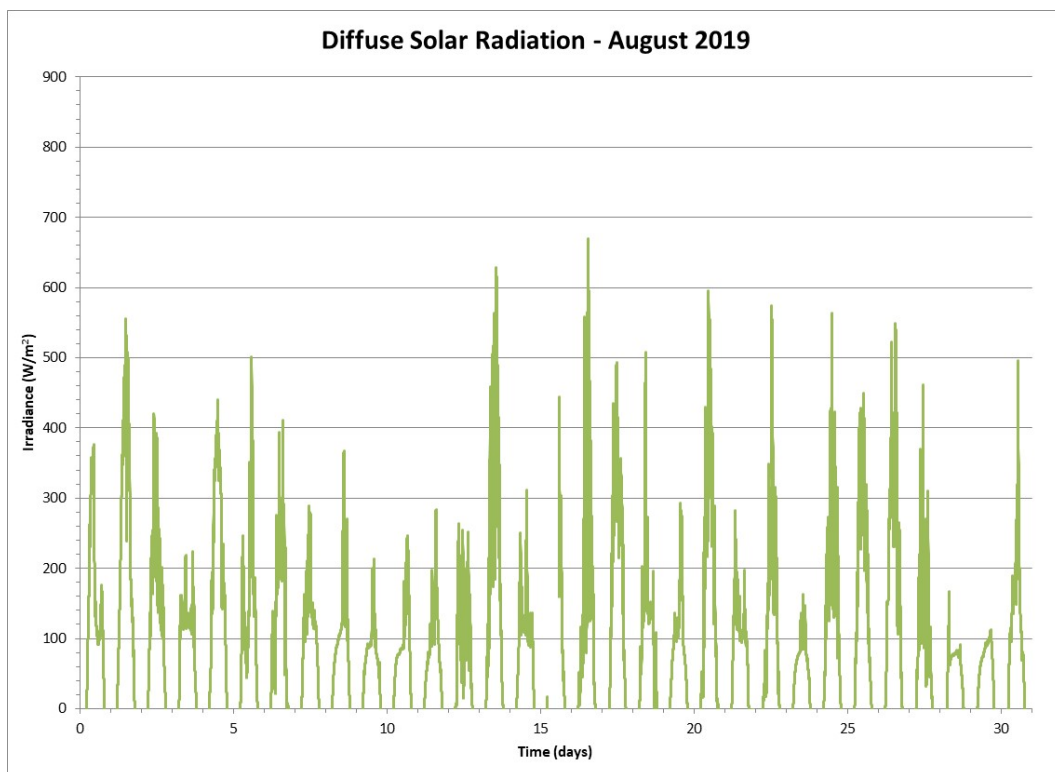


Figure 150 Diffuse Solar Radiation for the Month of August 2019

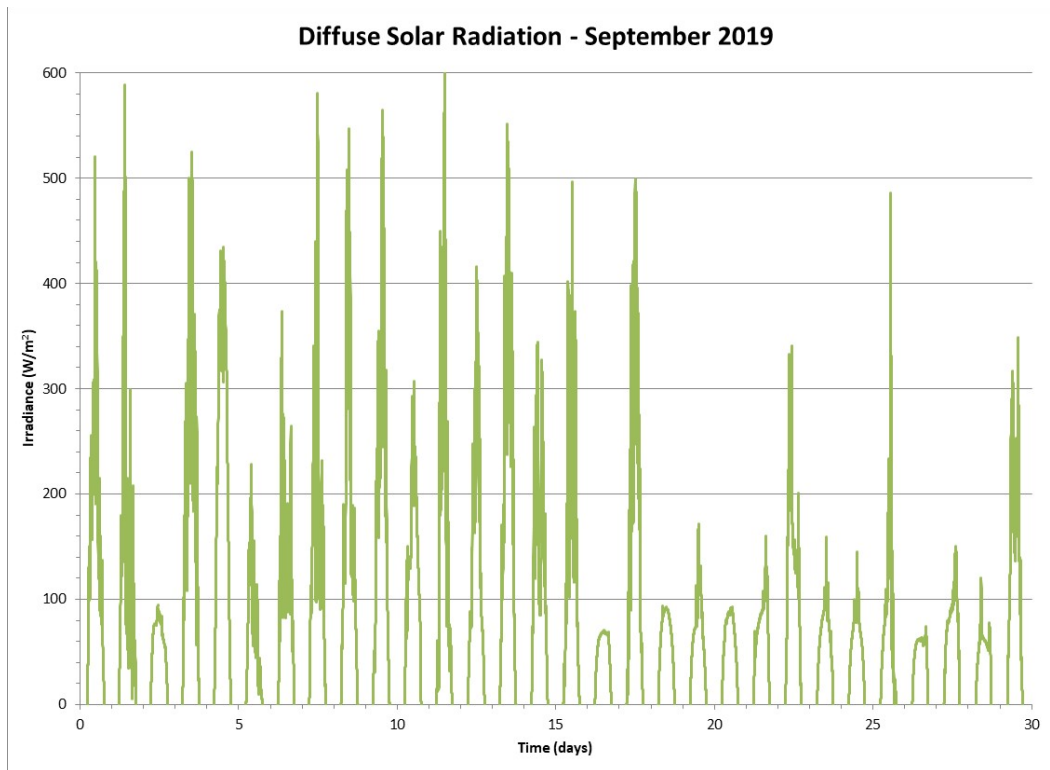


Figure 151 Diffuse Solar Radiation for the Month of September 2019

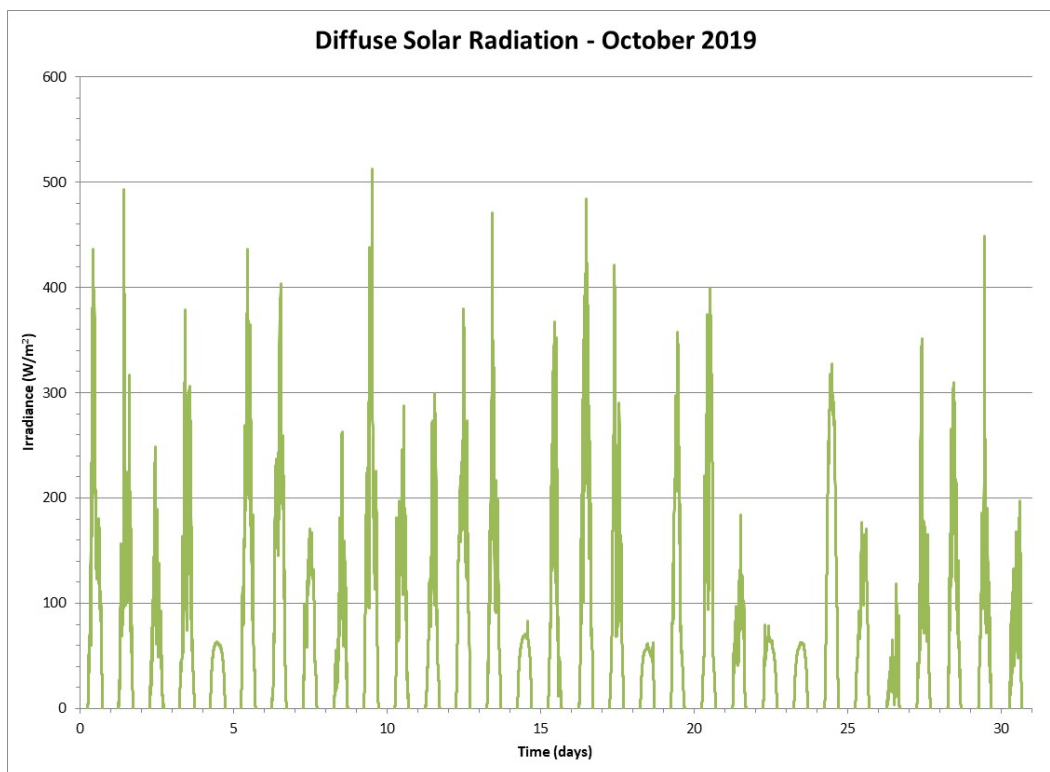


Figure 152 Diffuse Solar Radiation for the Month of October 2019

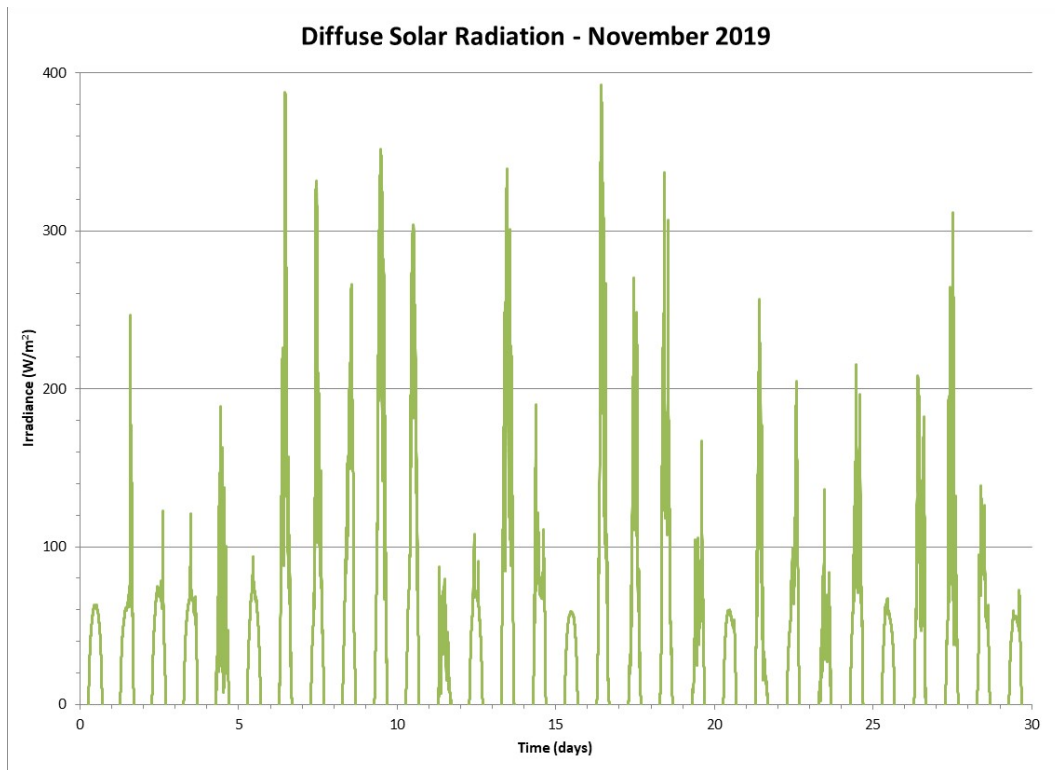


Figure 153 Diffuse Solar Radiation for the Month of November 2019

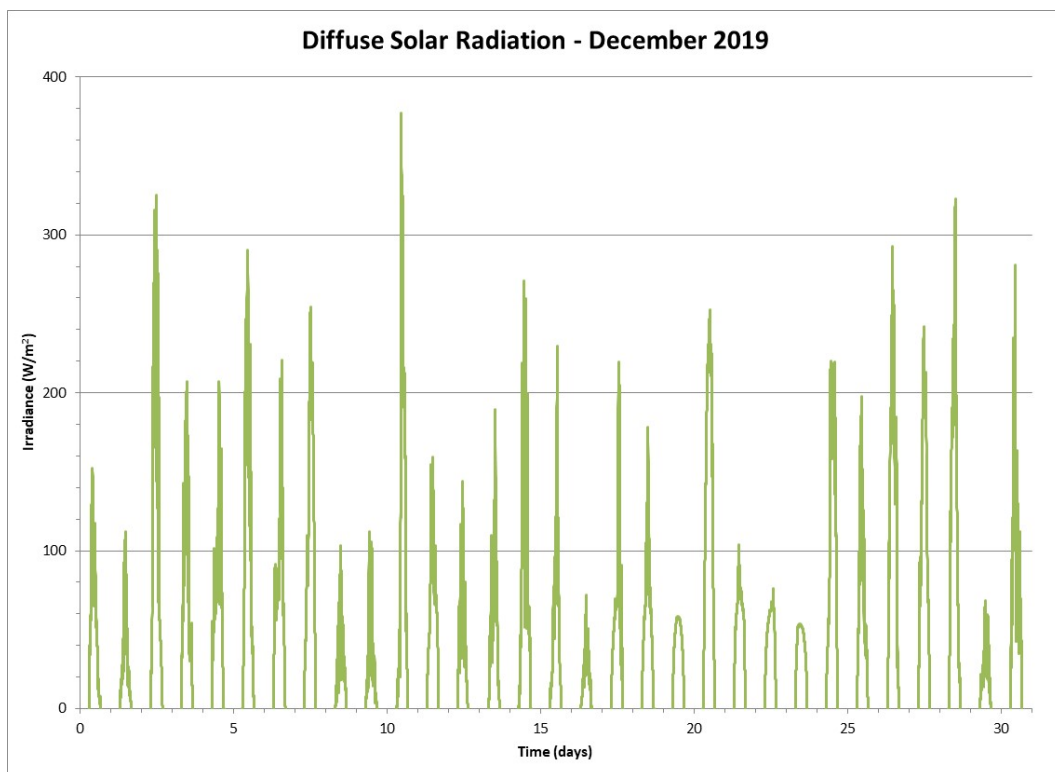


Figure 154 Diffuse Solar Radiation for the Month of December 2019

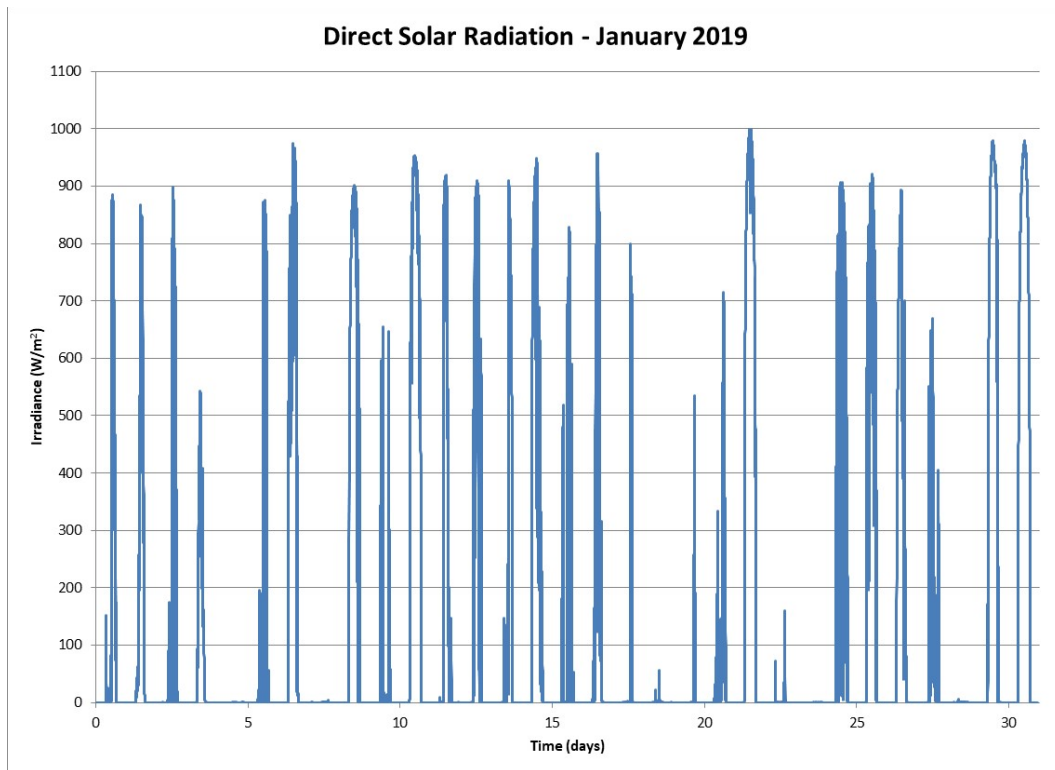


Figure 155 Direct Solar Radiation for the Month of January 2019

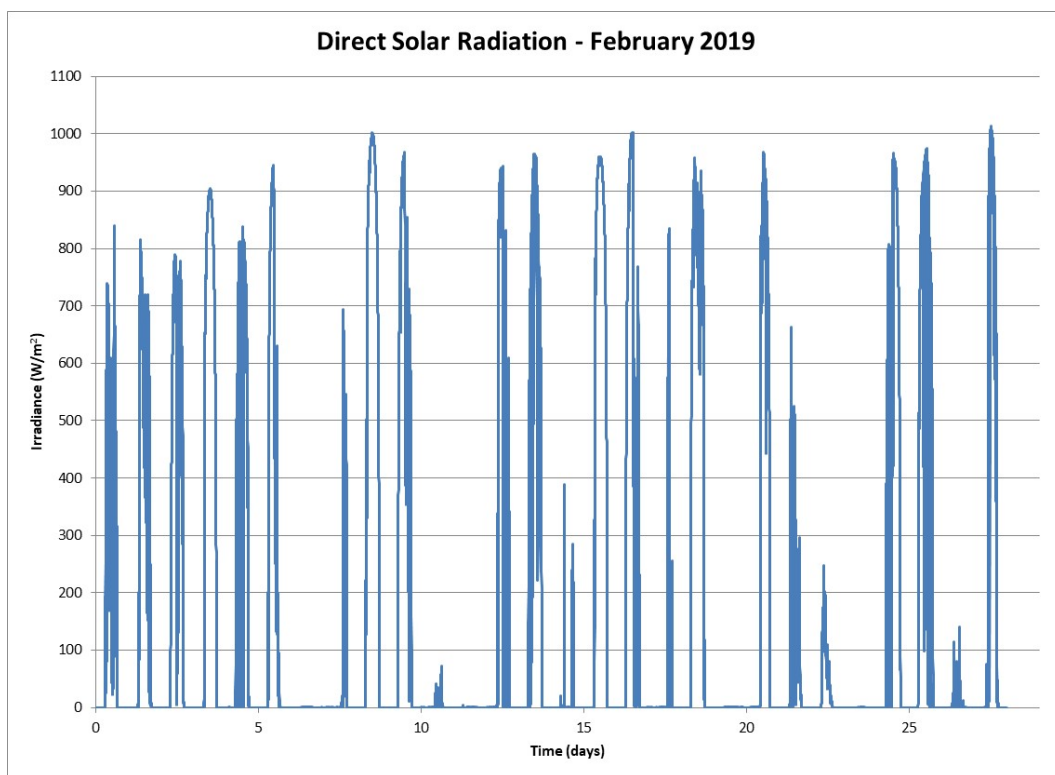


Figure 156 Direct Solar Radiation for the Month of February 2019

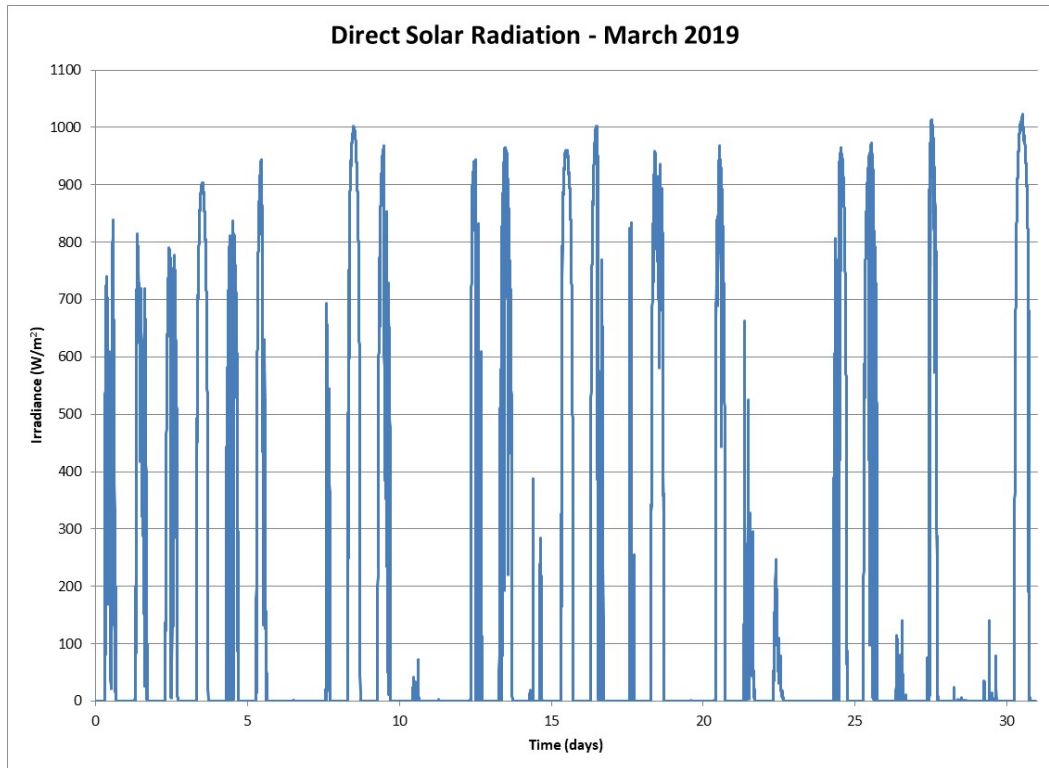


Figure 157 Direct Solar Radiation for the Month of March 2019

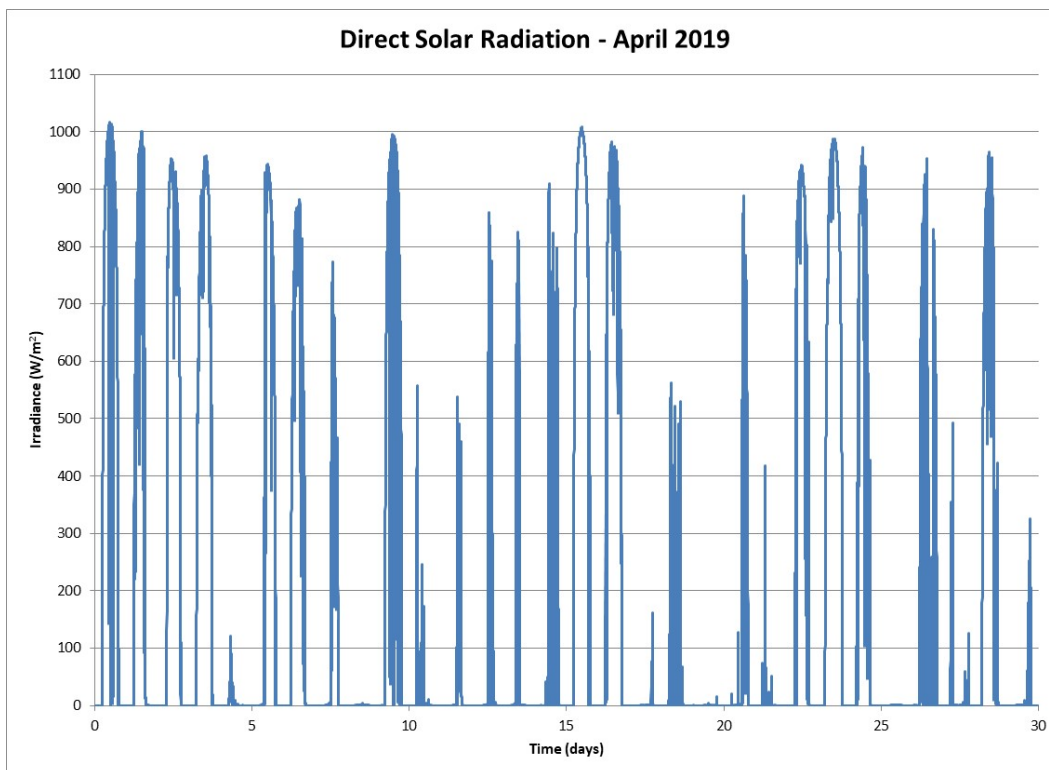


Figure 158 Direct Solar Radiation for the Month April 2019

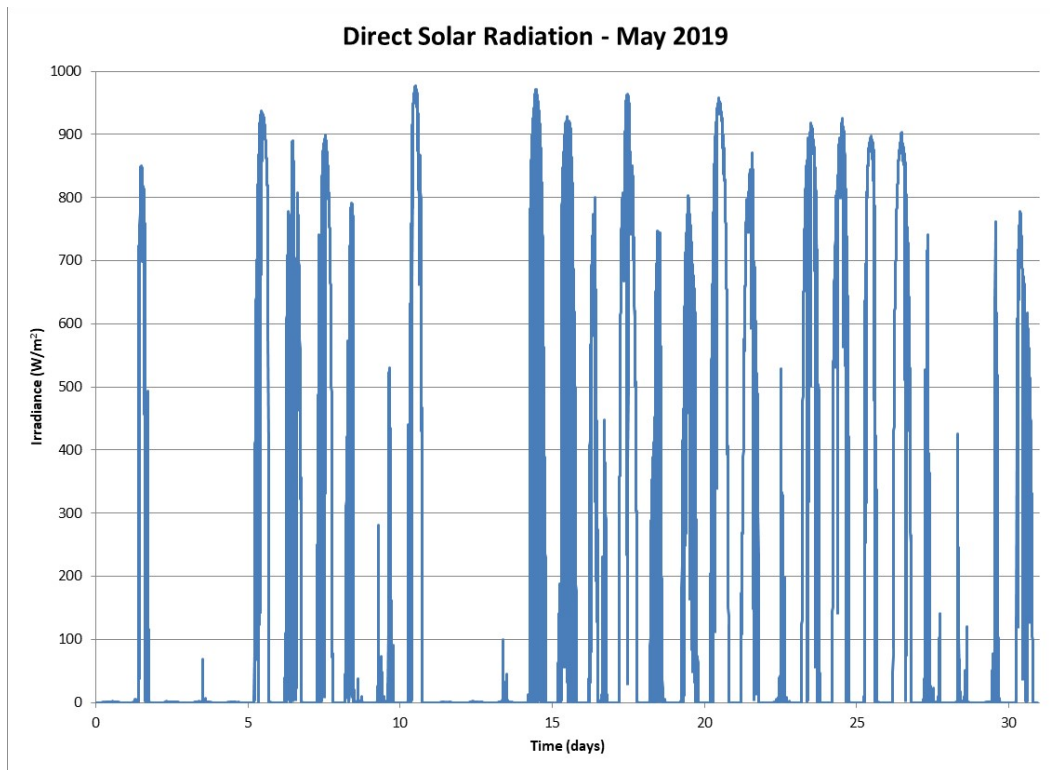


Figure 159 Direct Solar Radiation for the Month May 2019

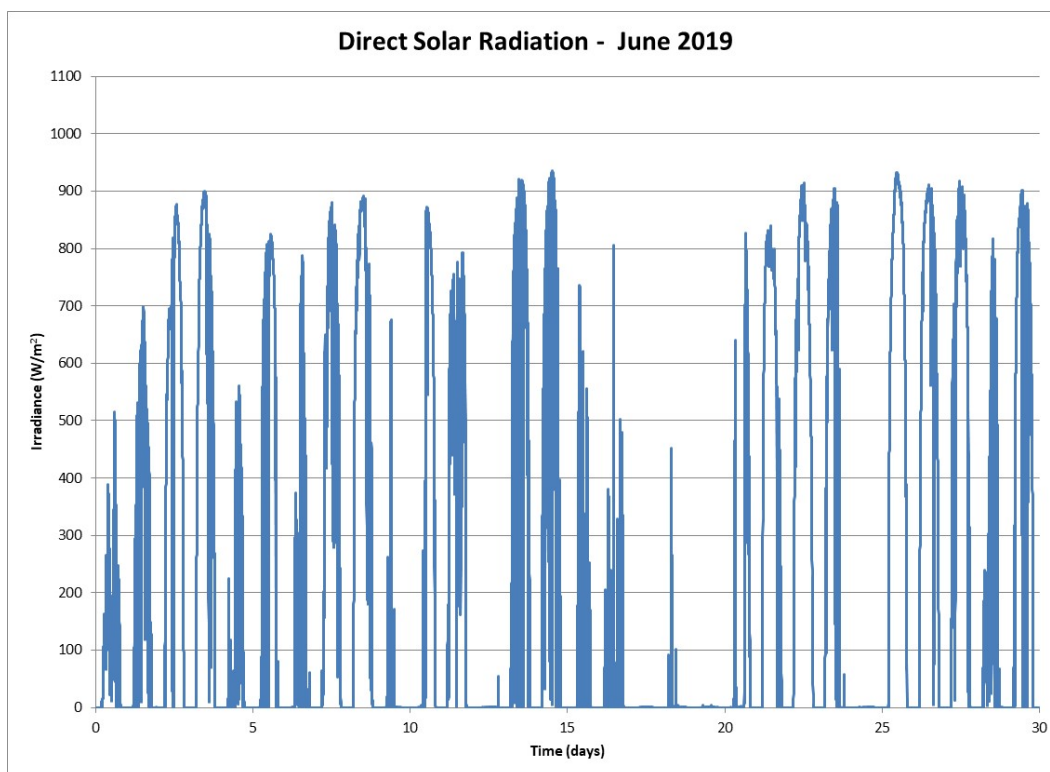


Figure 160 Direct Solar Radiation for the Month June 2019

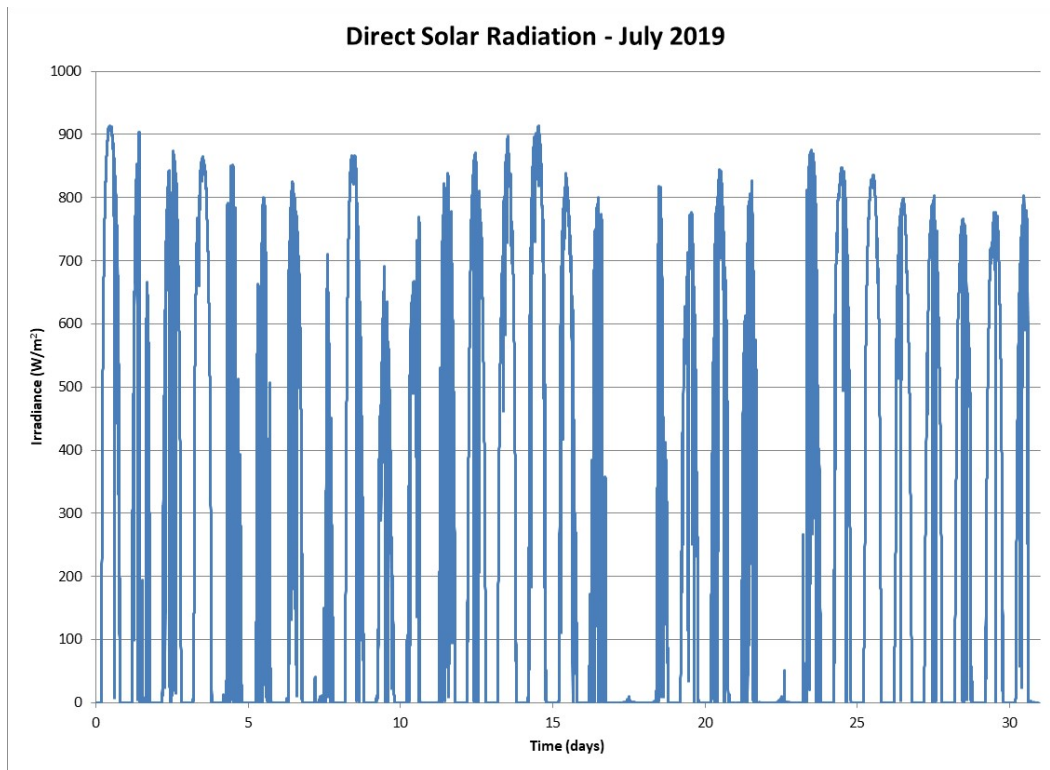


Figure 161 Direct Solar Radiation for the Month July 2019

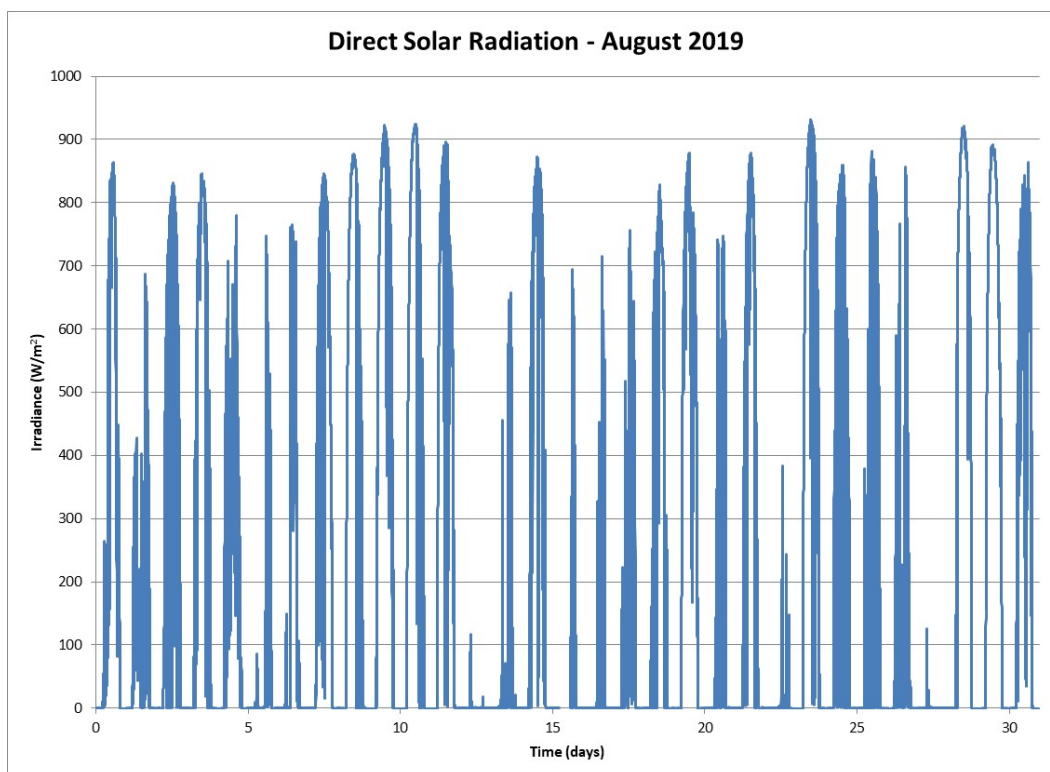


Figure 162 Direct Solar Radiation for the Month August 2019

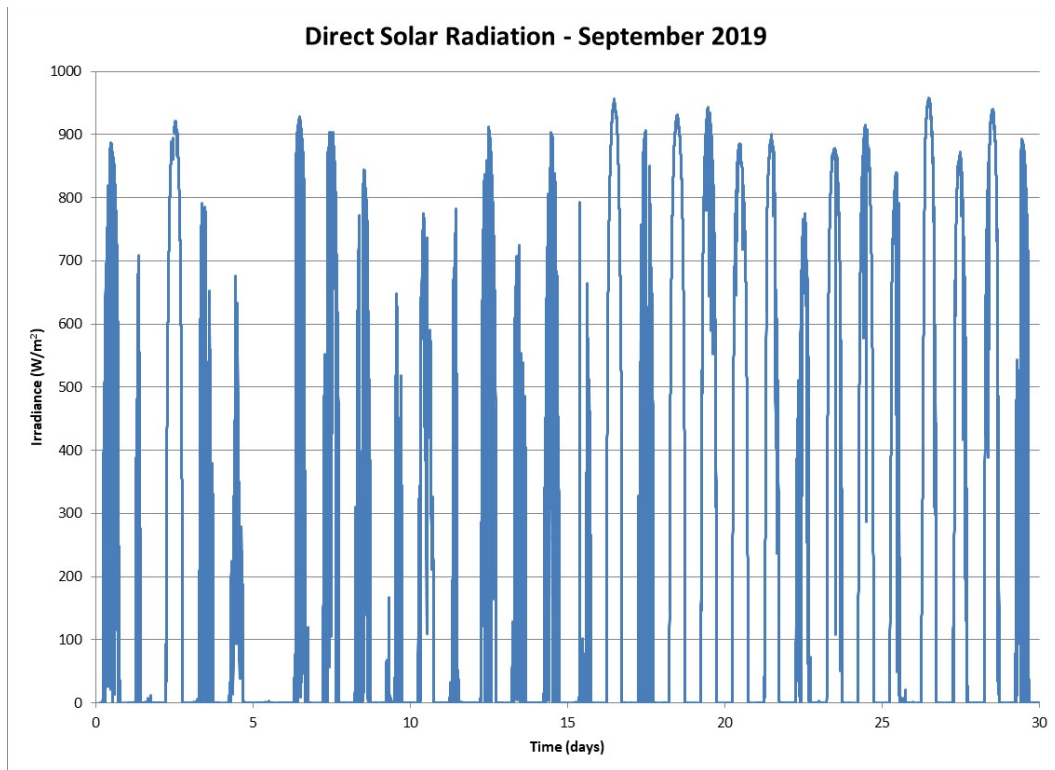


Figure 163 Direct Solar Radiation for the Month September 2019

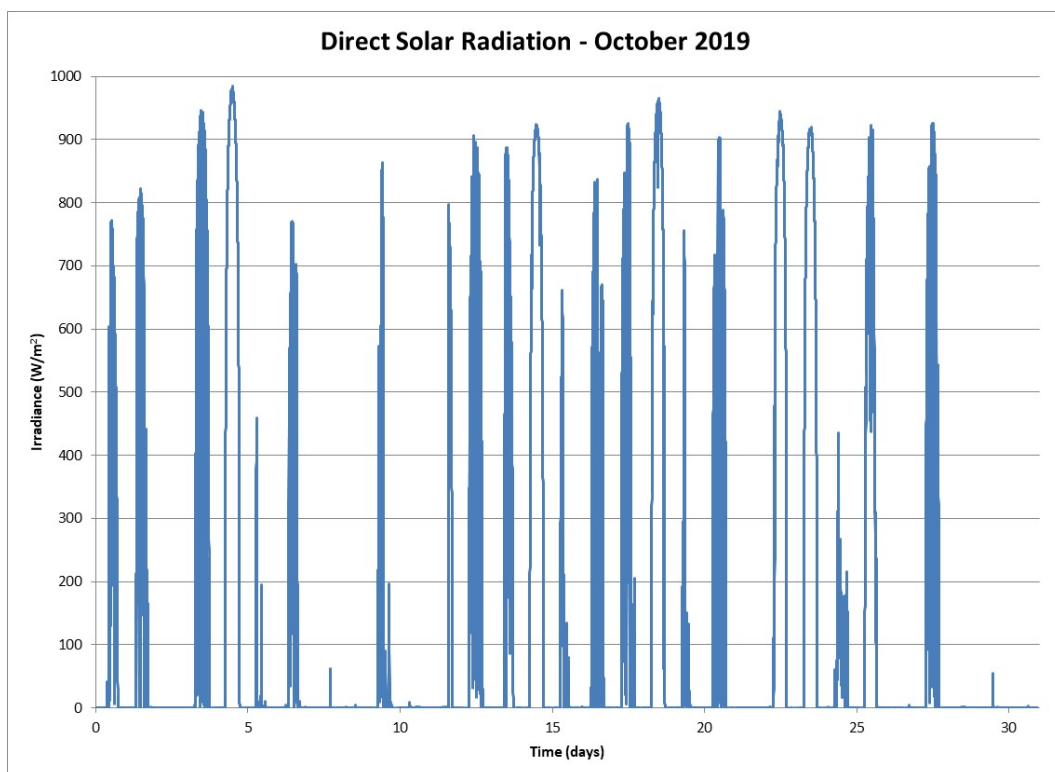


Figure 164 Direct Solar Radiation for the Month October 2019

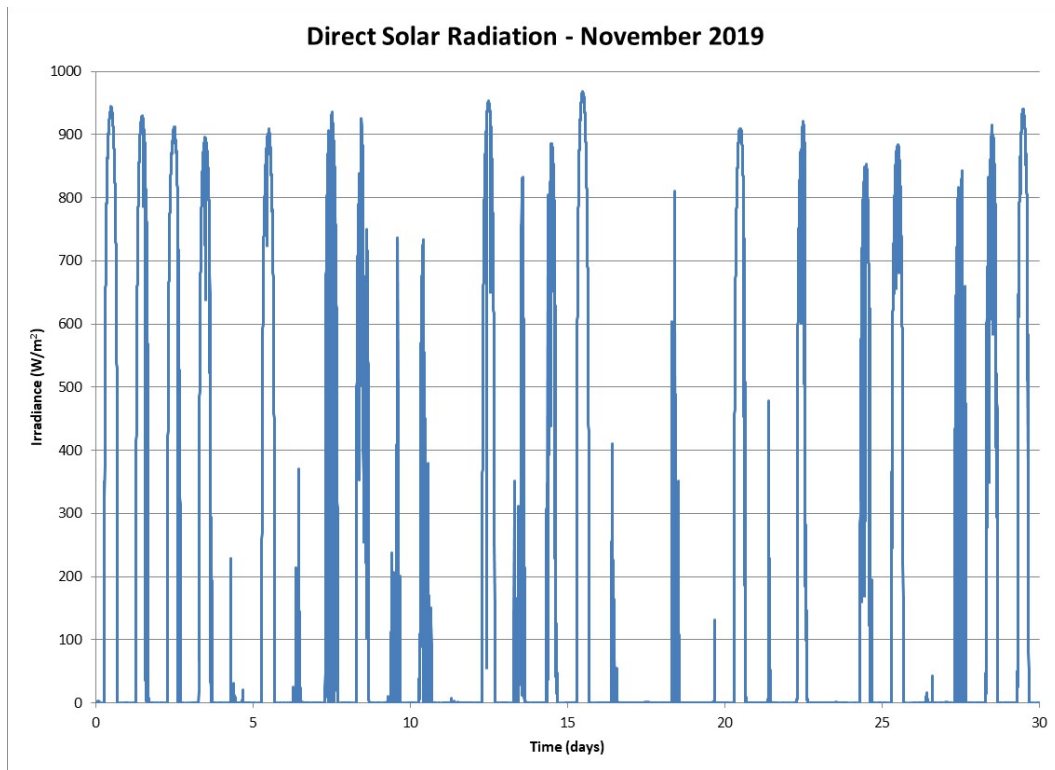


Figure 165 Direct Solar Radiation for the Month November 2019

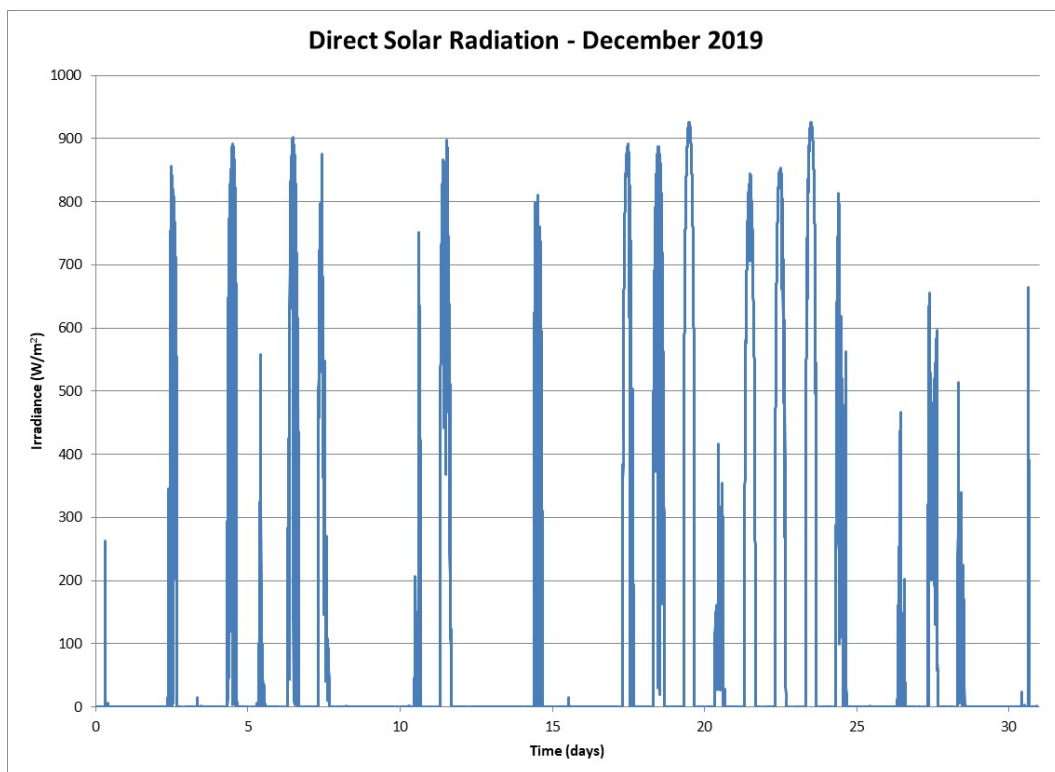


Figure 166 Direct Solar Radiation for the Month December 2019

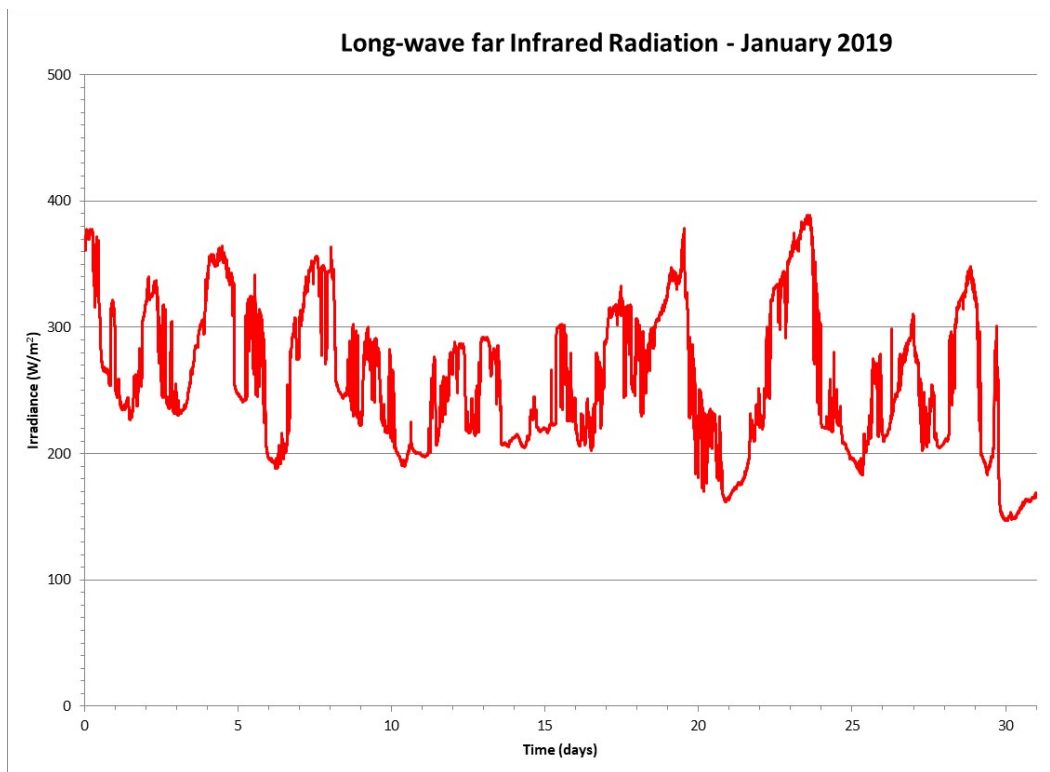


Figure 167 Long-wave Far Infrared Radiation for the Month of January 2019

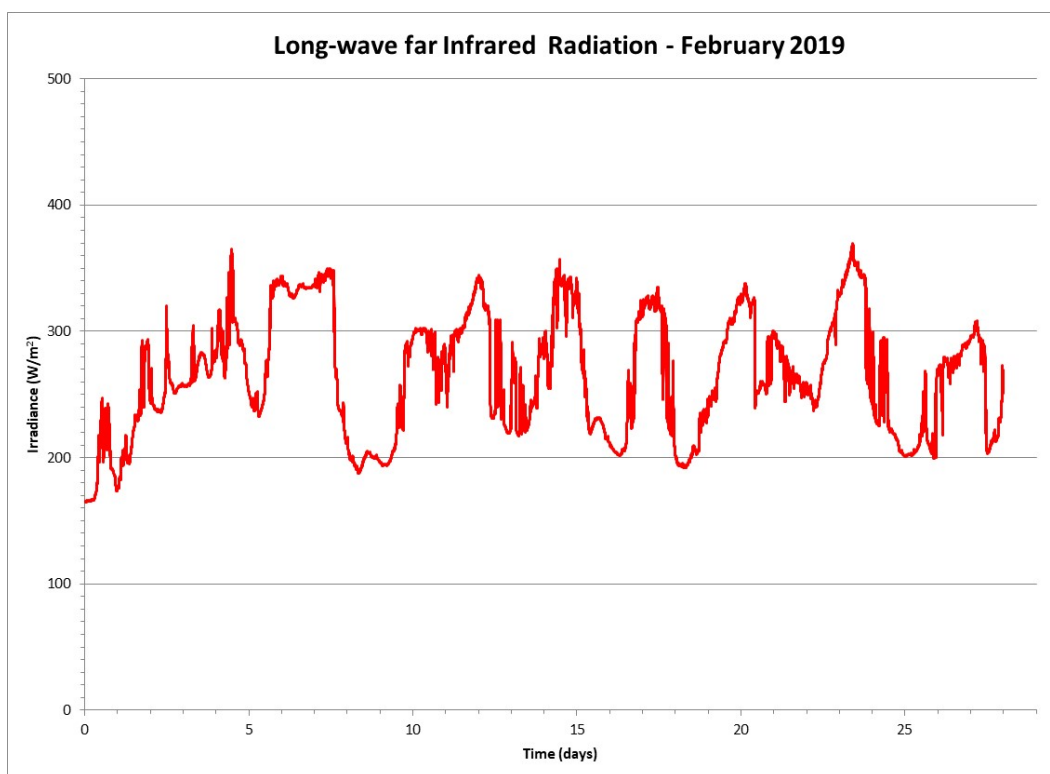


Figure 168 Long-wave Far Infrared Radiation for the Month of February 2019

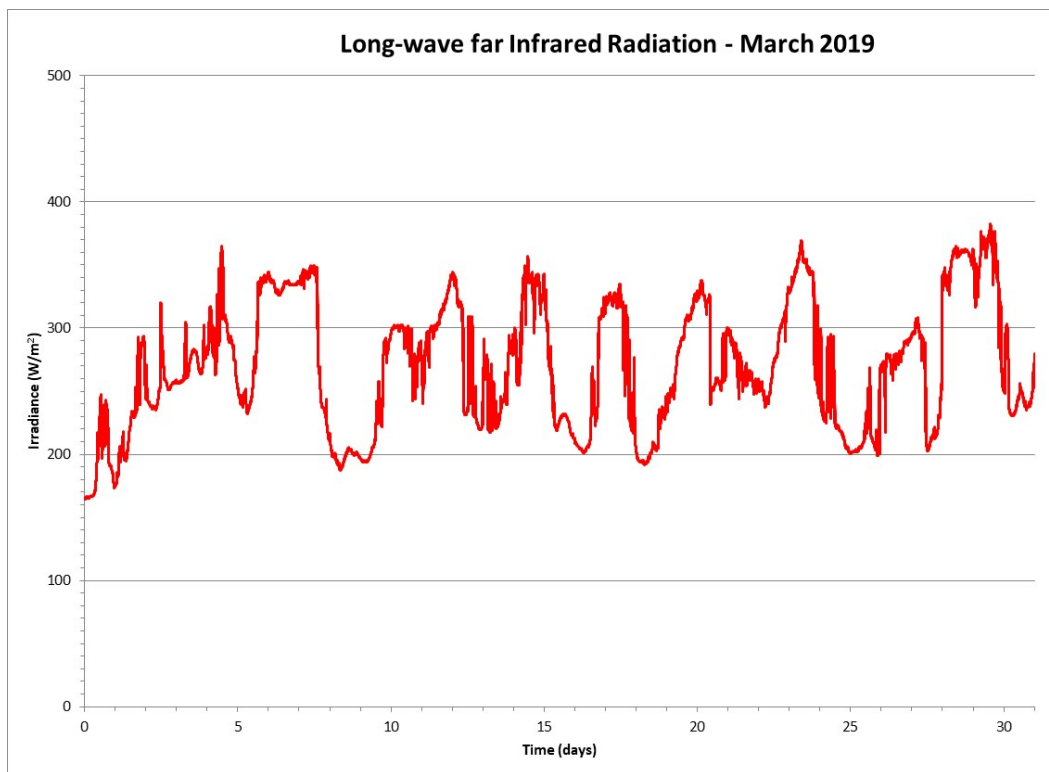


Figure 169 Long-wave Far Infrared Radiation for the Month of March 2019

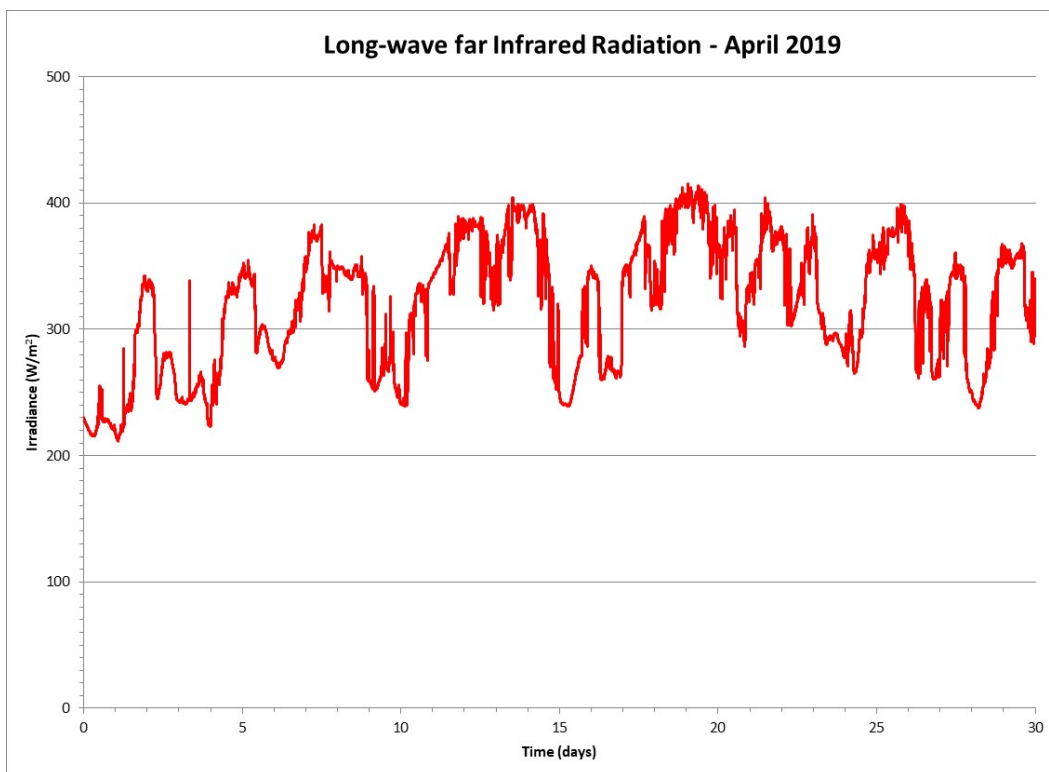


Figure 170 Long-wave Far Infrared Radiation for the Month of April 2019

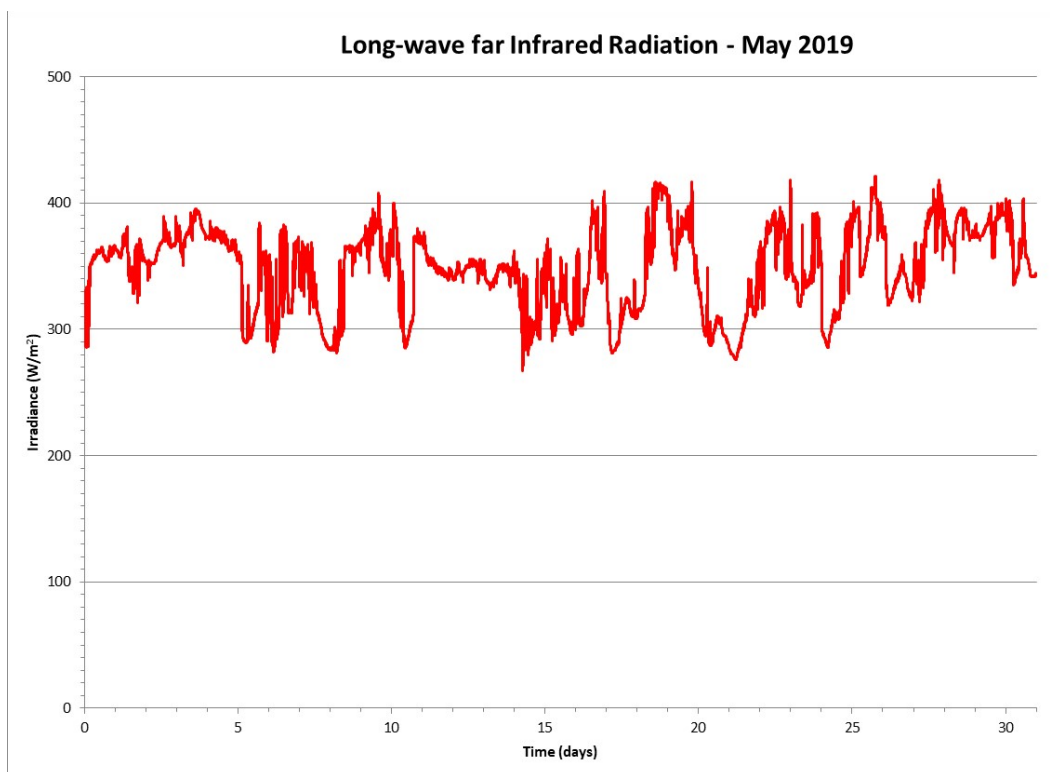


Figure 171 Long-wave Far Infrared Radiation for the Month of May 2019

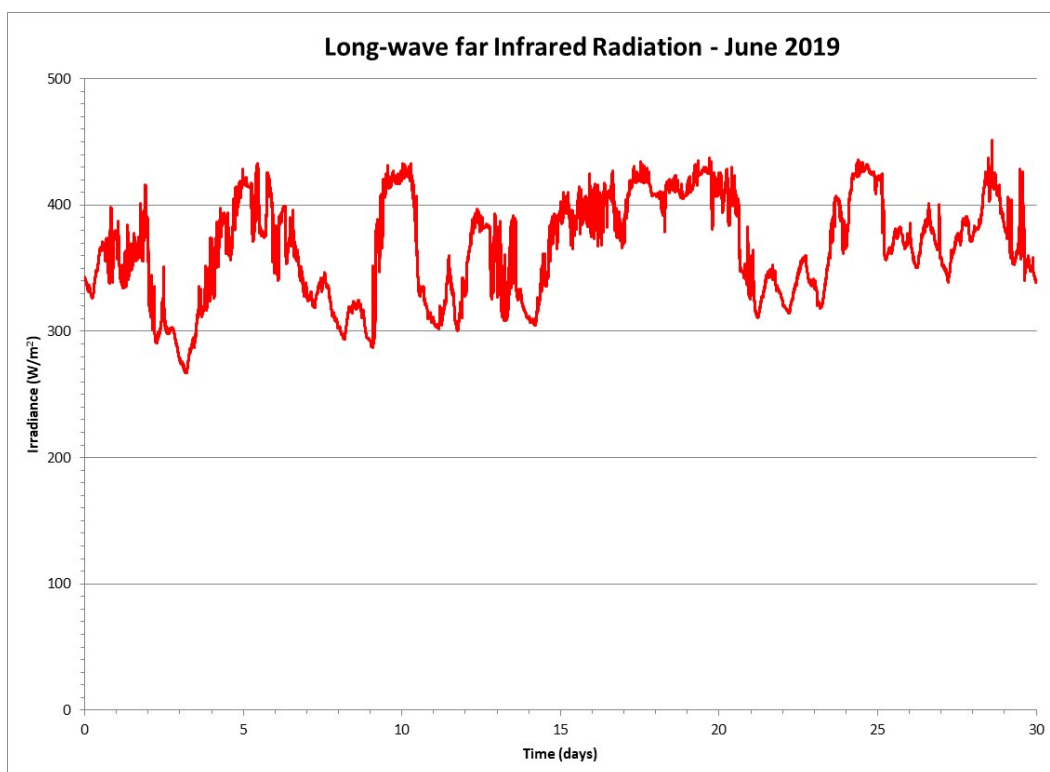


Figure 172 Long-wave Far Infrared Radiation for the Month of June 2019

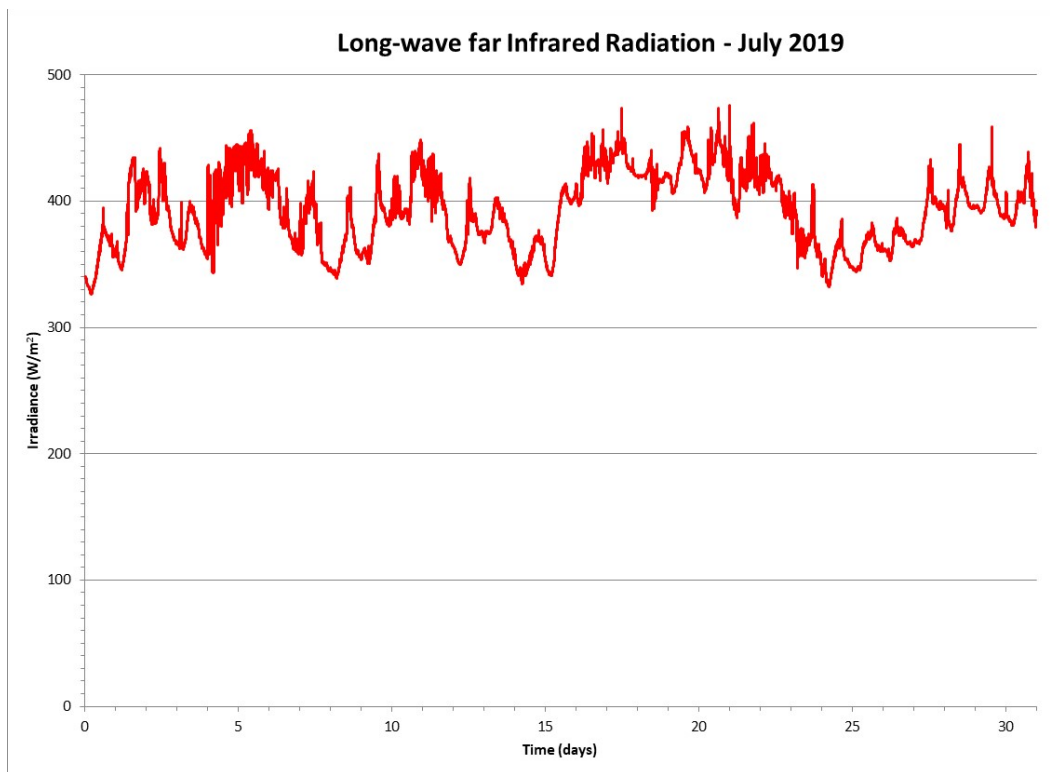


Figure 173 Long-wave Far Infrared Radiation for the Month of July 2019

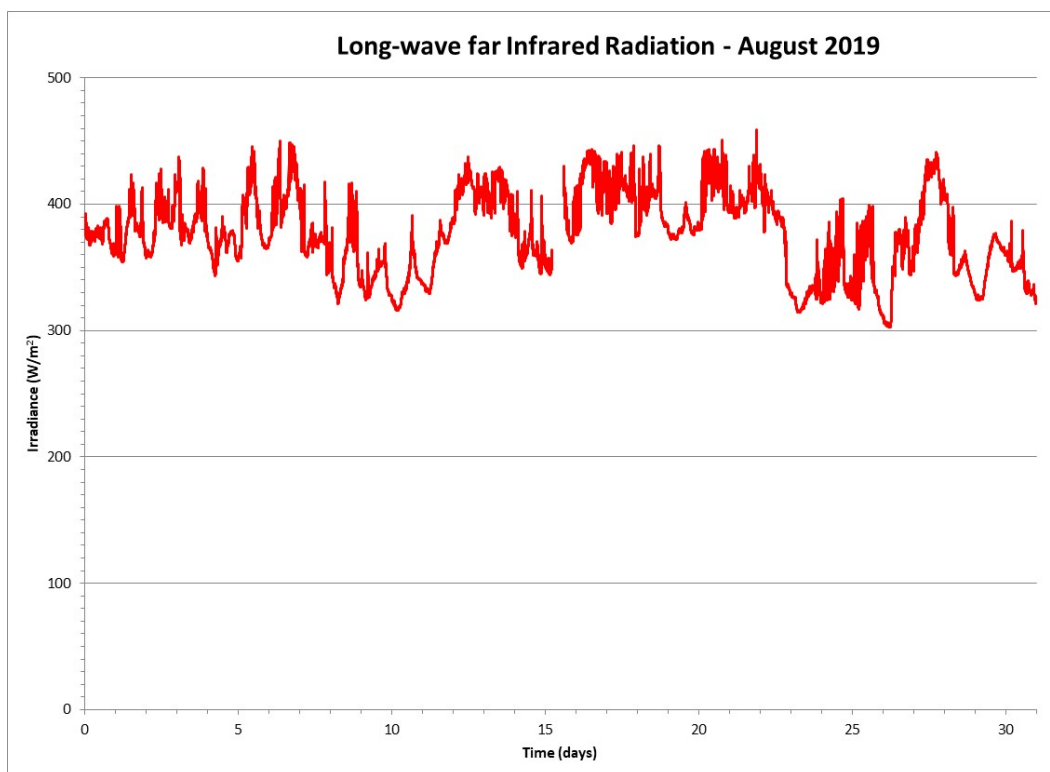


Figure 174 Long-wave Far Infrared Radiation for the Month of August 2019

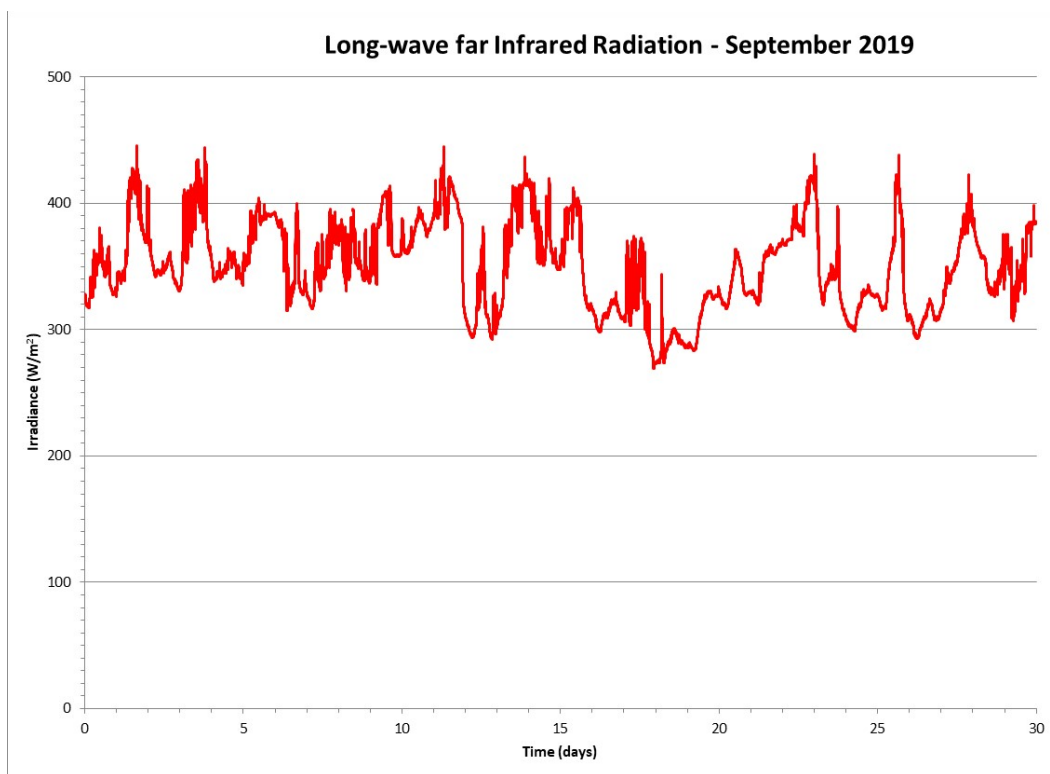


Figure 175 Long-wave Far Infrared Radiation for the Month of September 2019

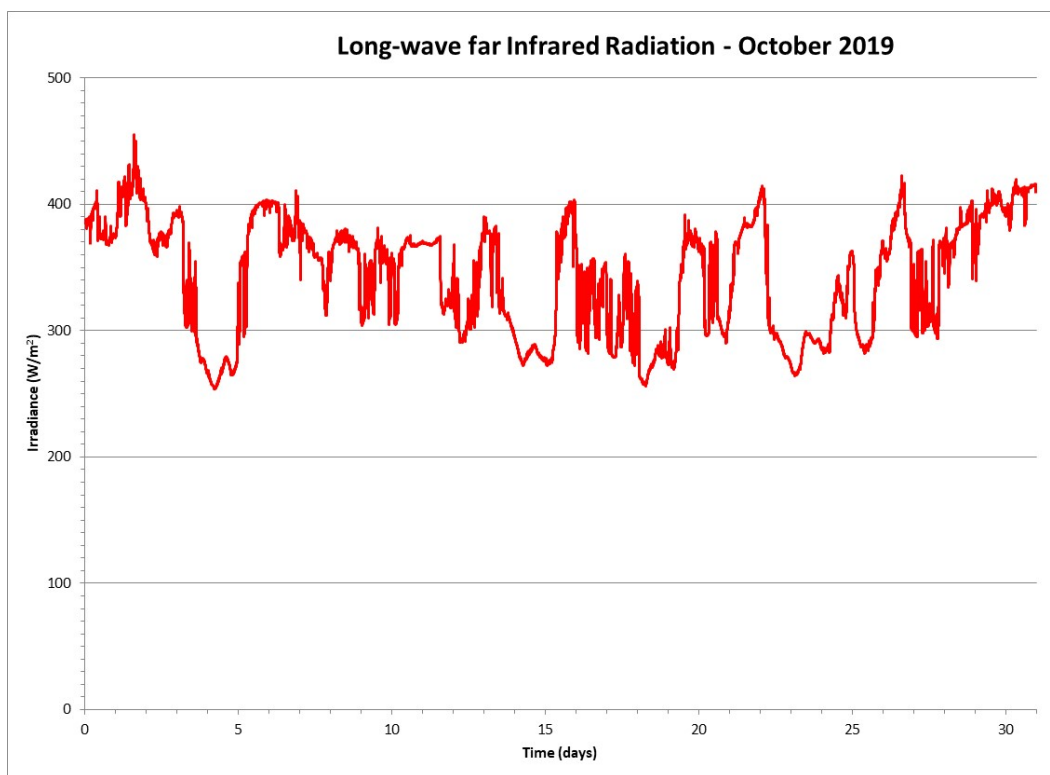


Figure 176 Long-wave Far Infrared Radiation for the Month of October 2019

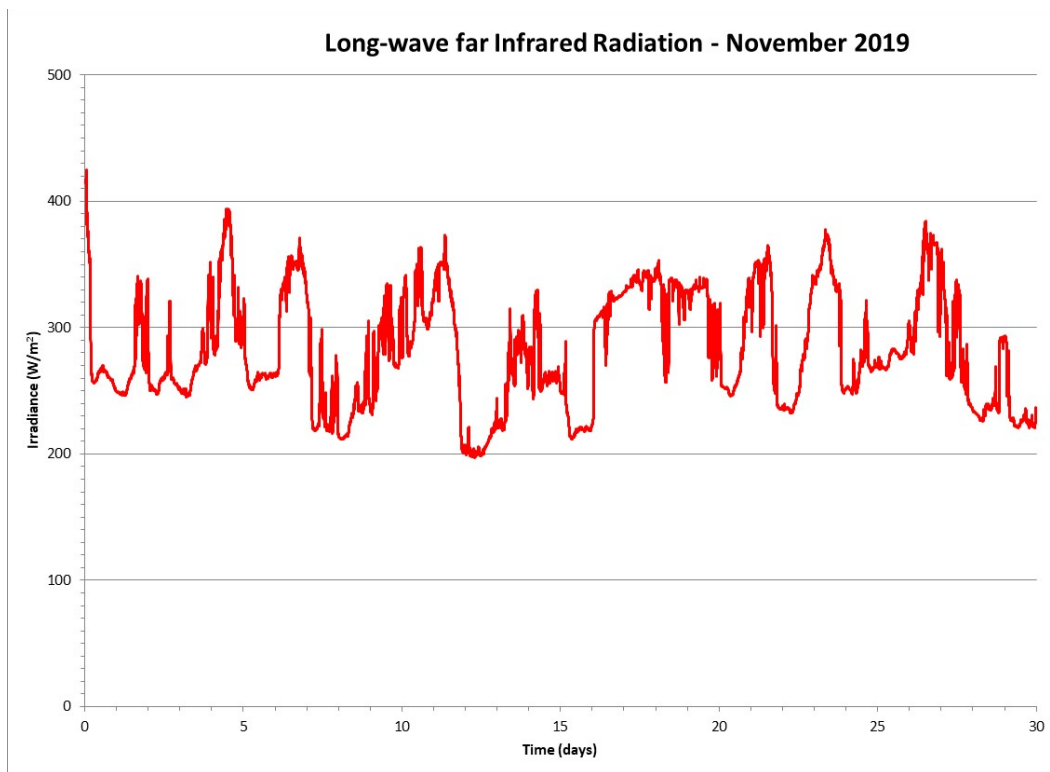


Figure 177 Long-wave Far Infrared Radiation for the Month of November 2019

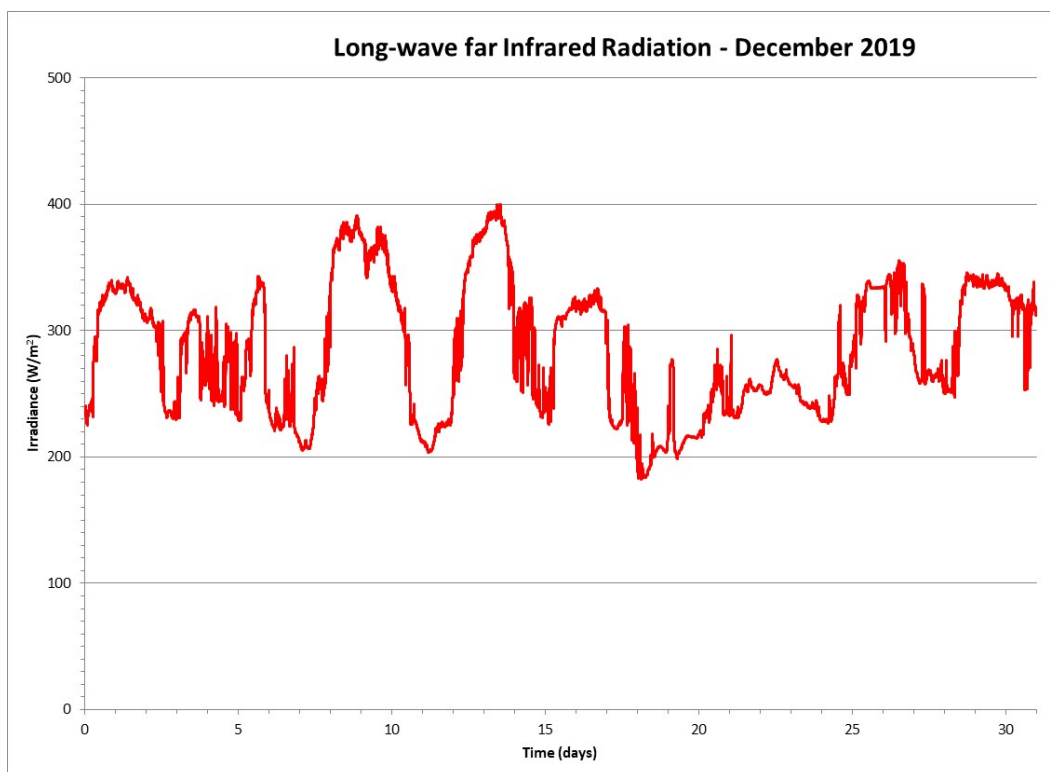


Figure 178 Long-wave Far Infrared Radiation for the Month of December 2019

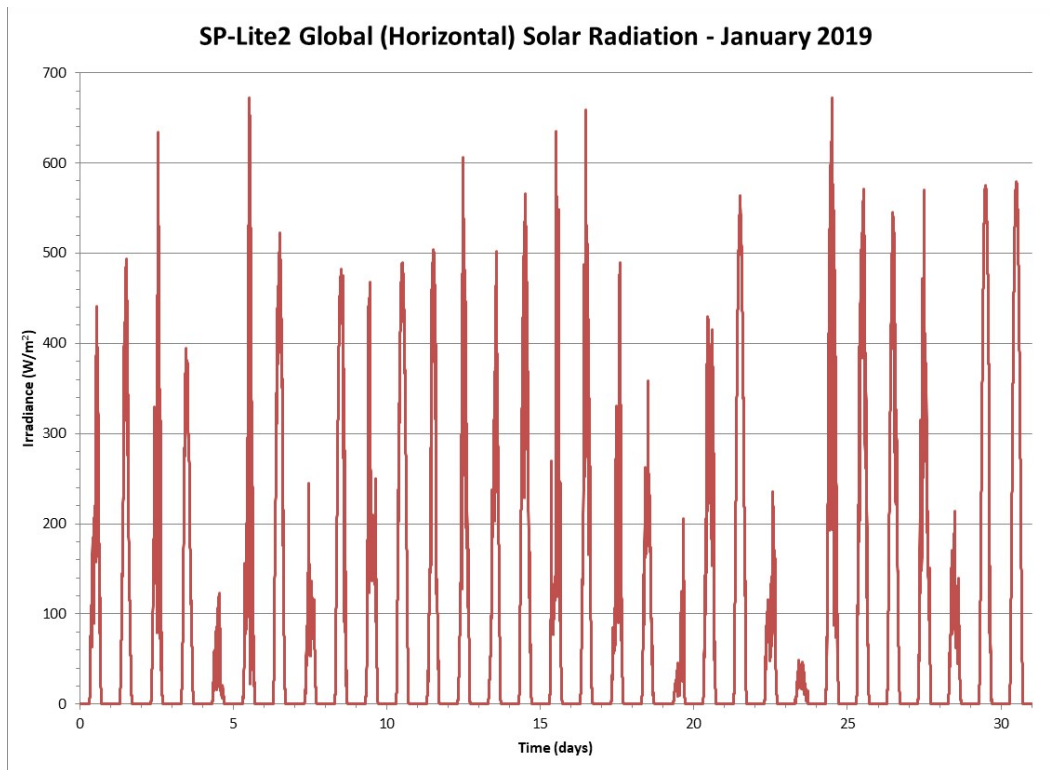


Figure 179 Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of January 2019

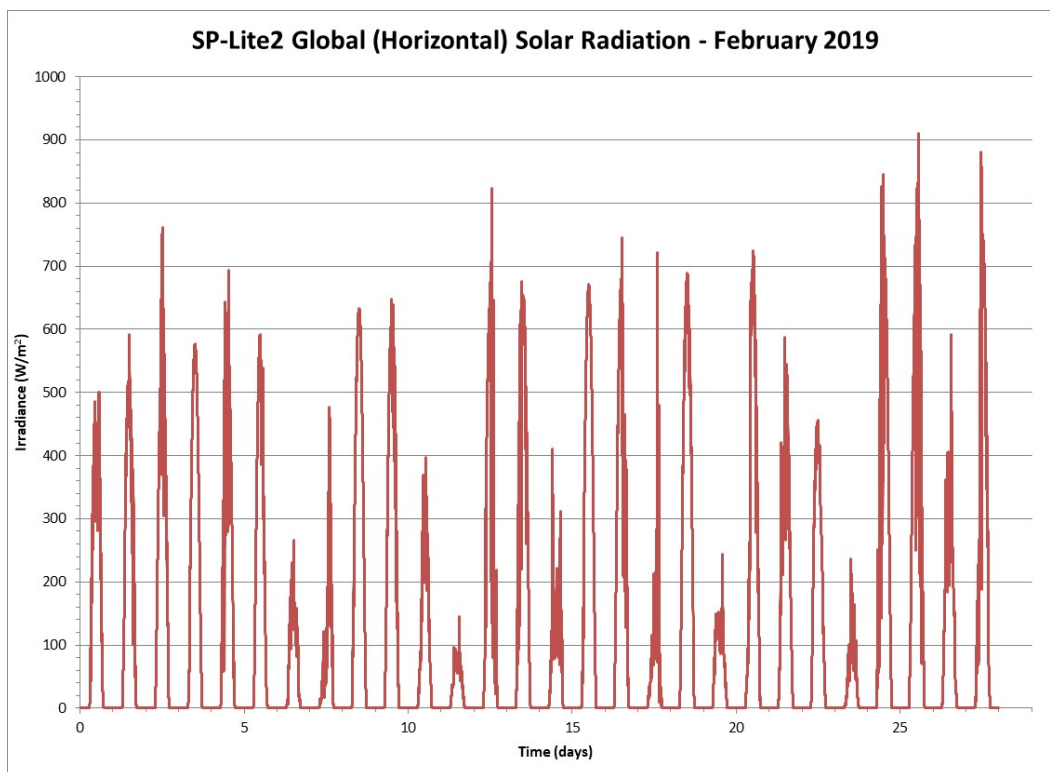


Figure 180 Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of February 2019

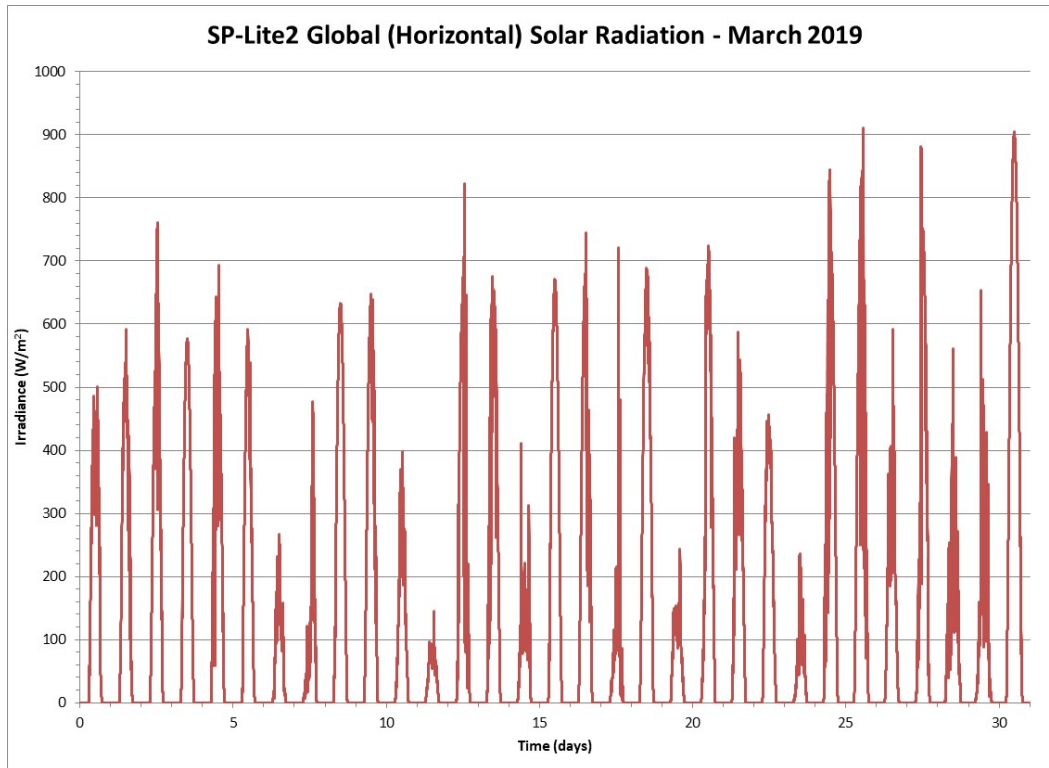


Figure 181 Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of March 2019

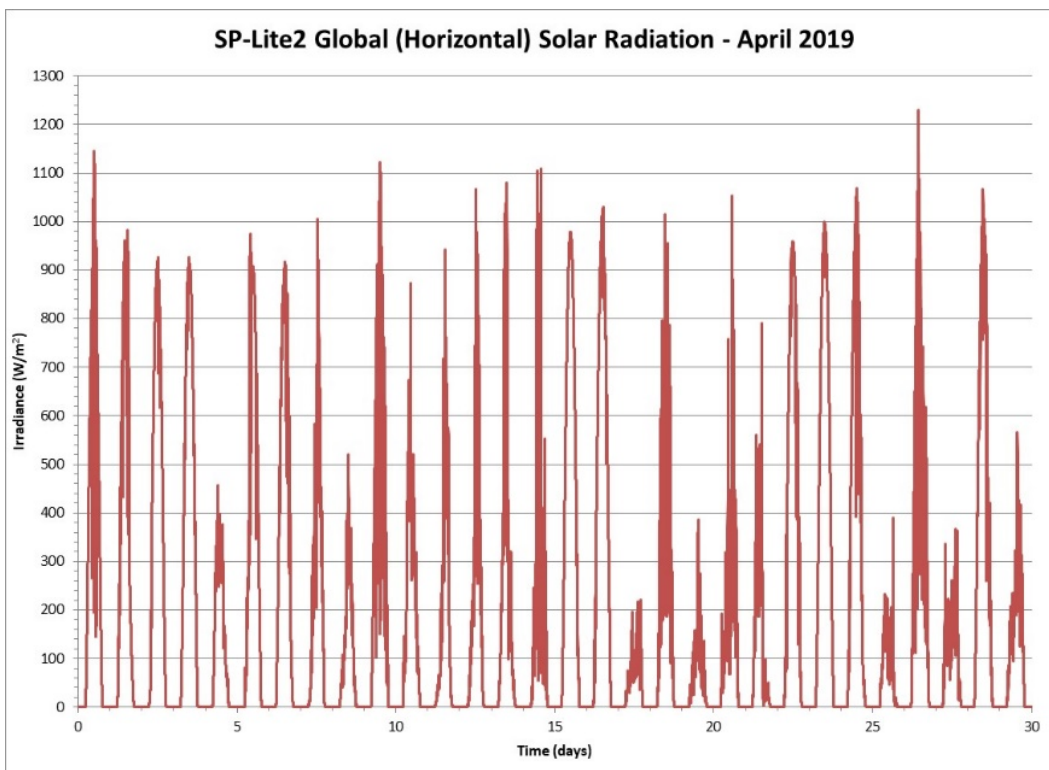


Figure 182 Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of April 2019

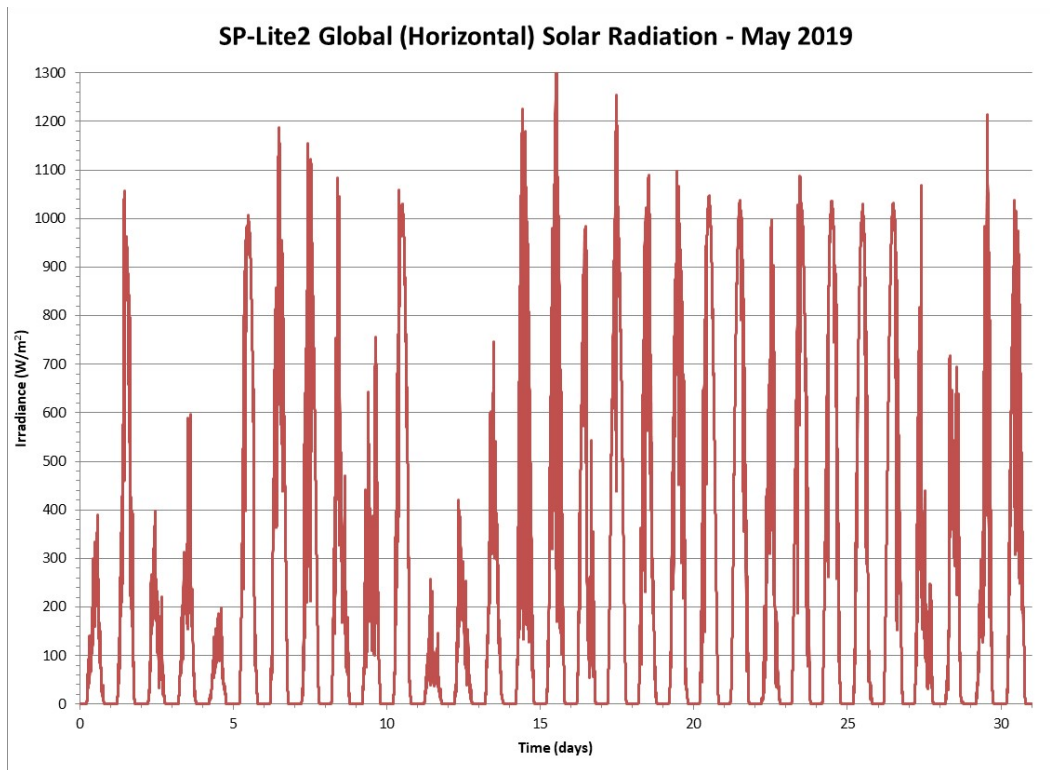


Figure 183 Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of May 2019

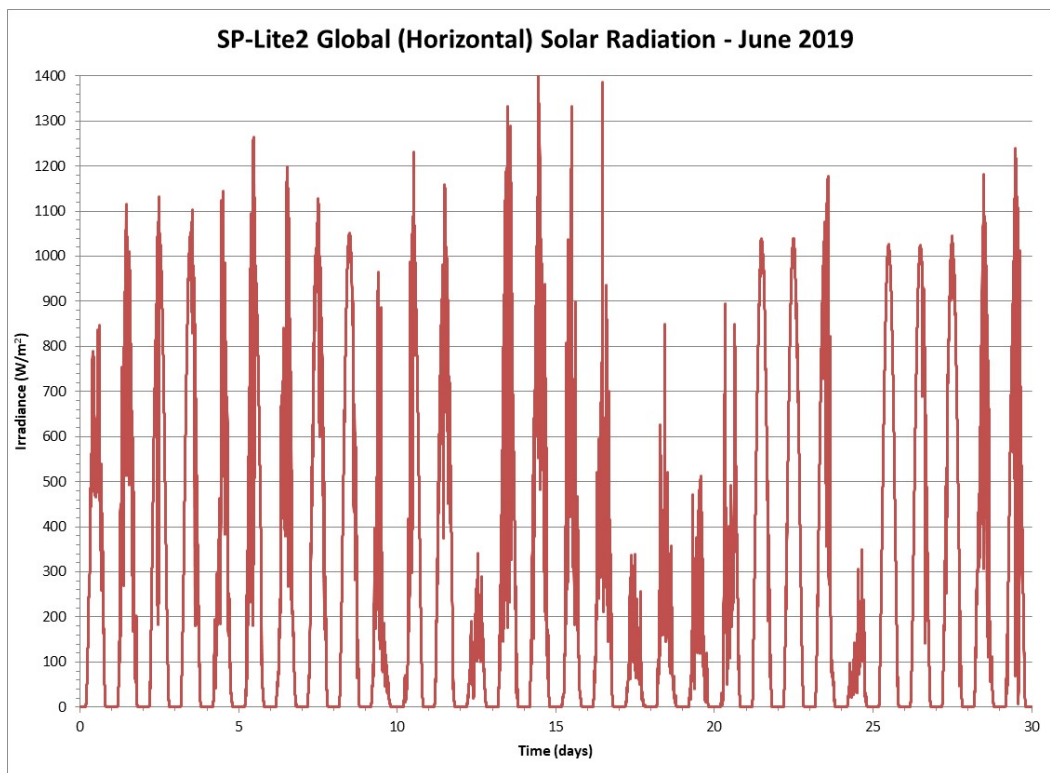


Figure 184 Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of June 2019

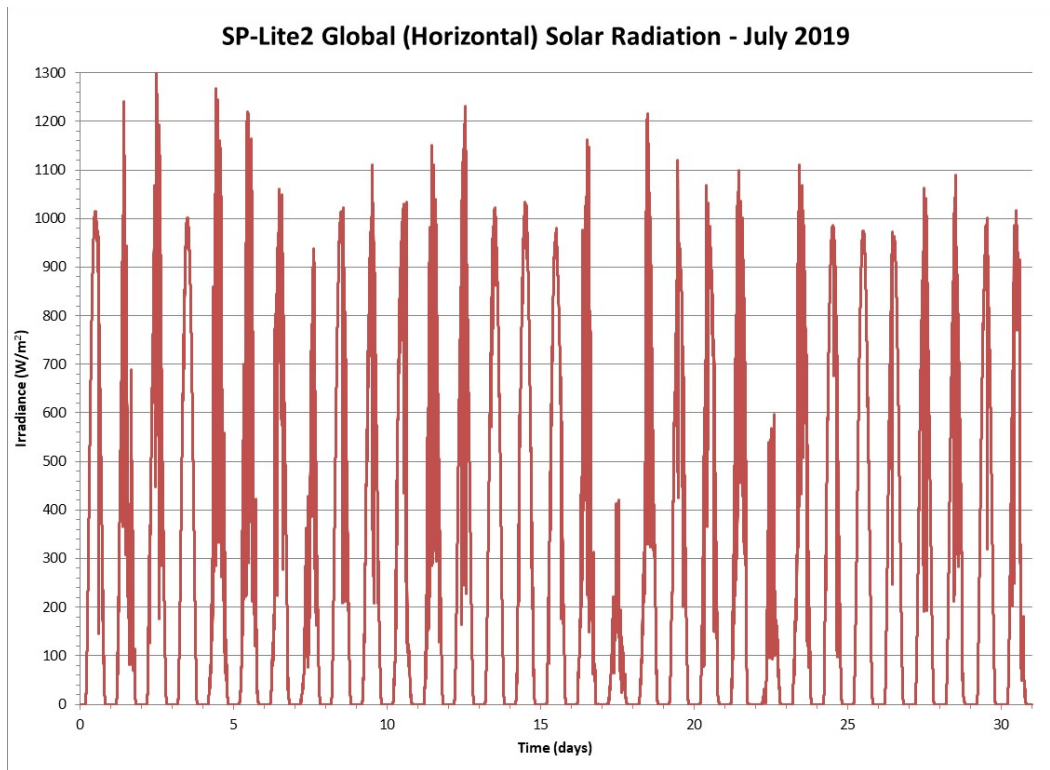


Figure 18551 Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of July 2019

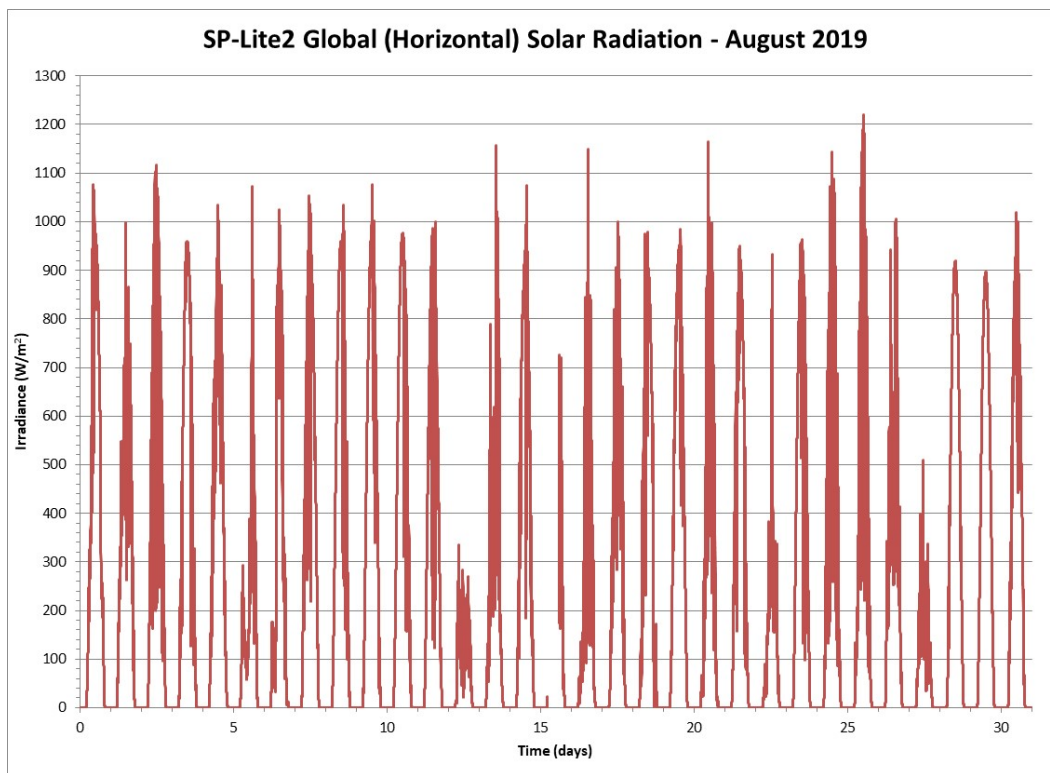


Figure 186 Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of August 2019

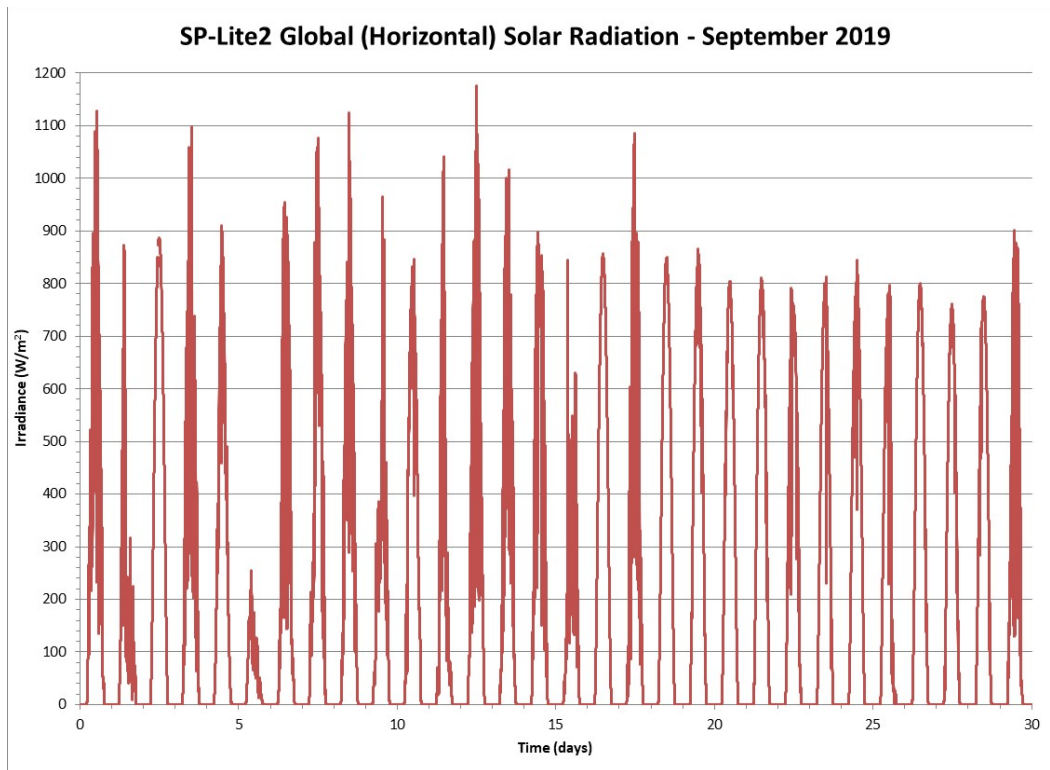


Figure 187 Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of September 2019

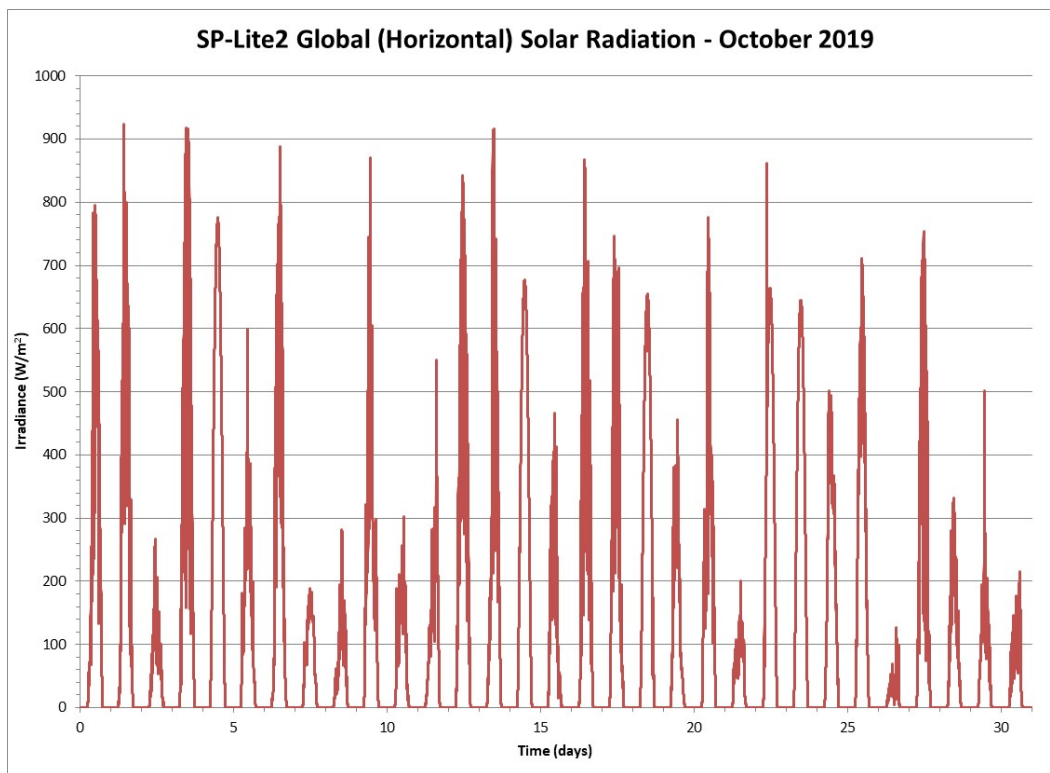


Figure 188 Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of October 2019

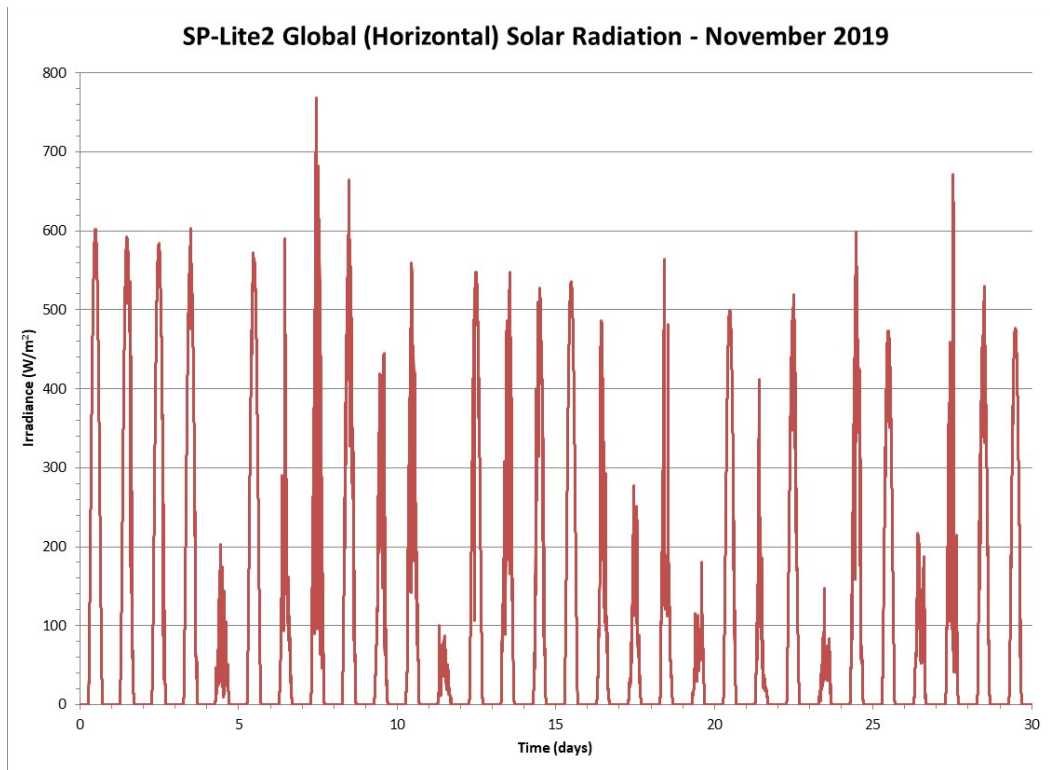


Figure 189 Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of November 2019

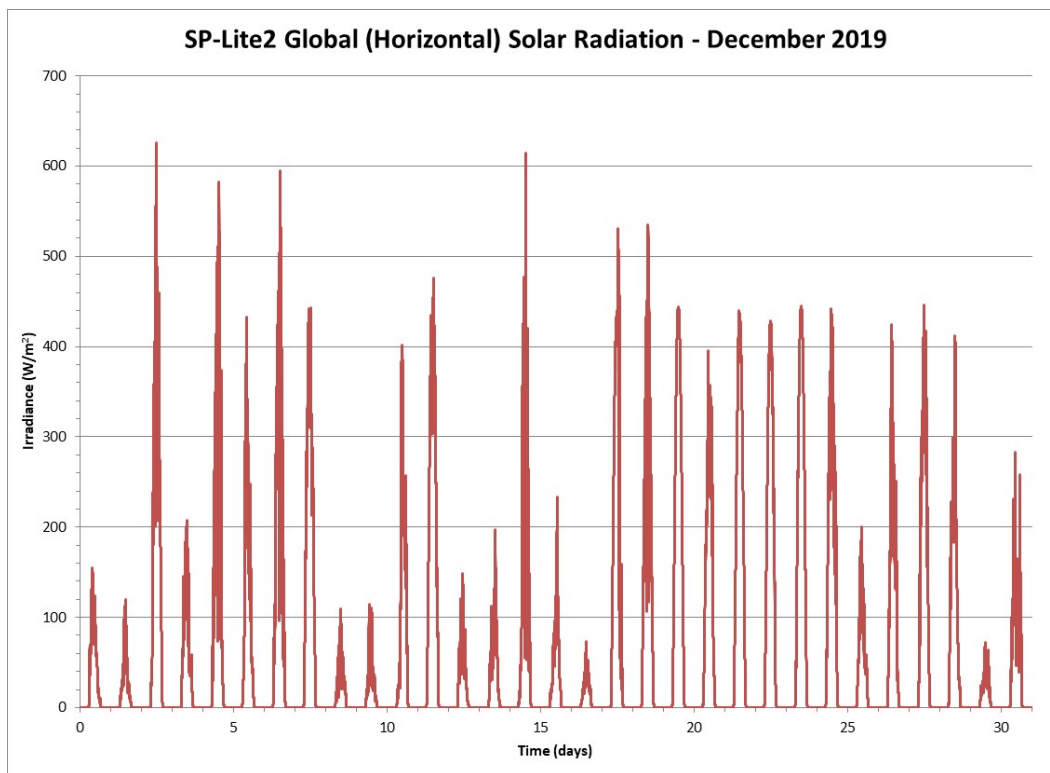


Figure 190 Global Solar Radiation from an SP-Lite2 Pyranometer for the Month of December 2019

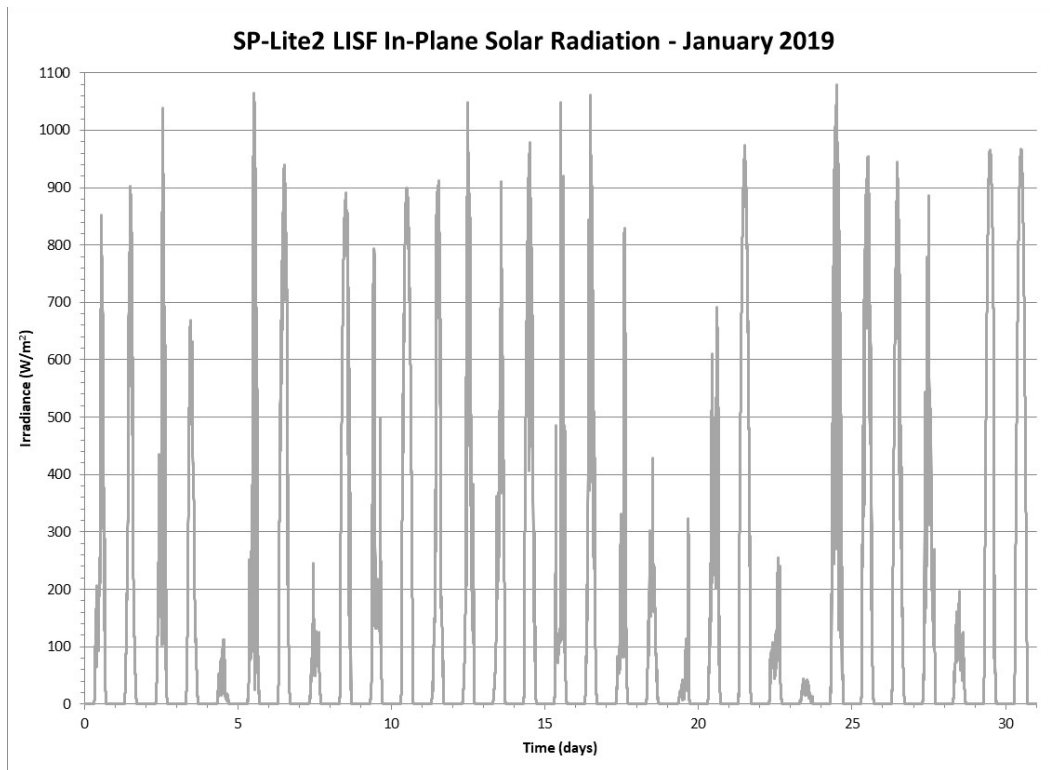


Figure 191 Tilted ( $27^\circ$ ) Global Solar Radiation from an SP-Lite2 Pyranometer for January 2019

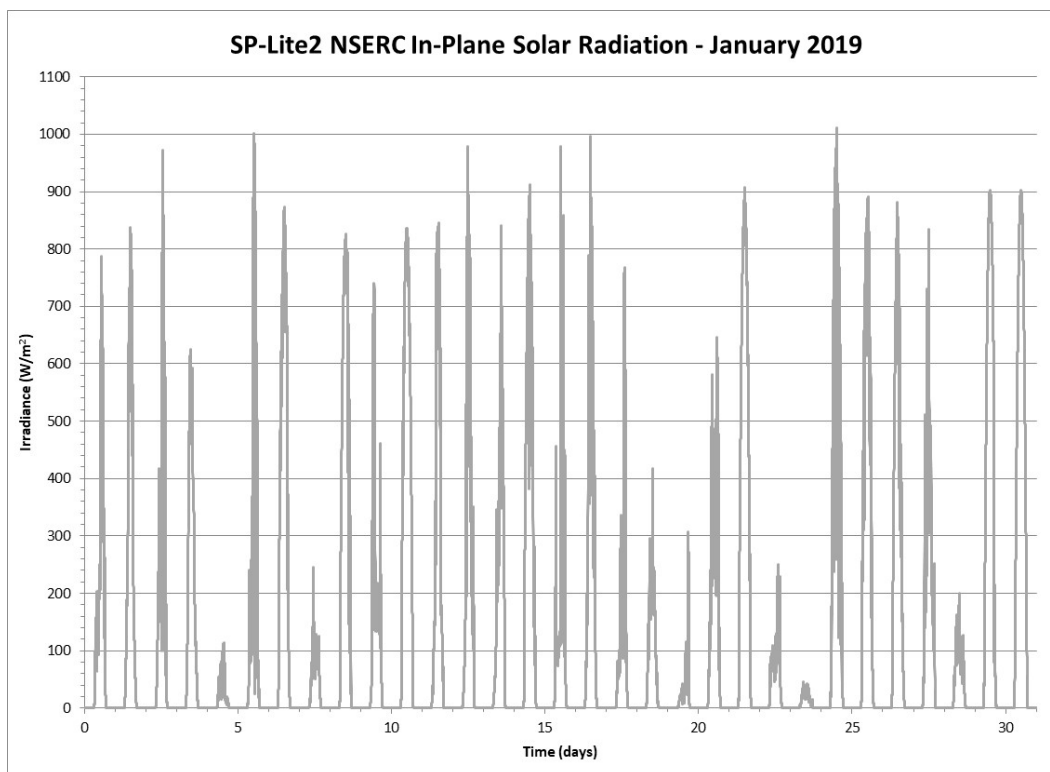


Figure 192 Tilted ( $23^\circ$ ) Global Solar Radiation from an SP-Lite2 Pyranometer for January 2019

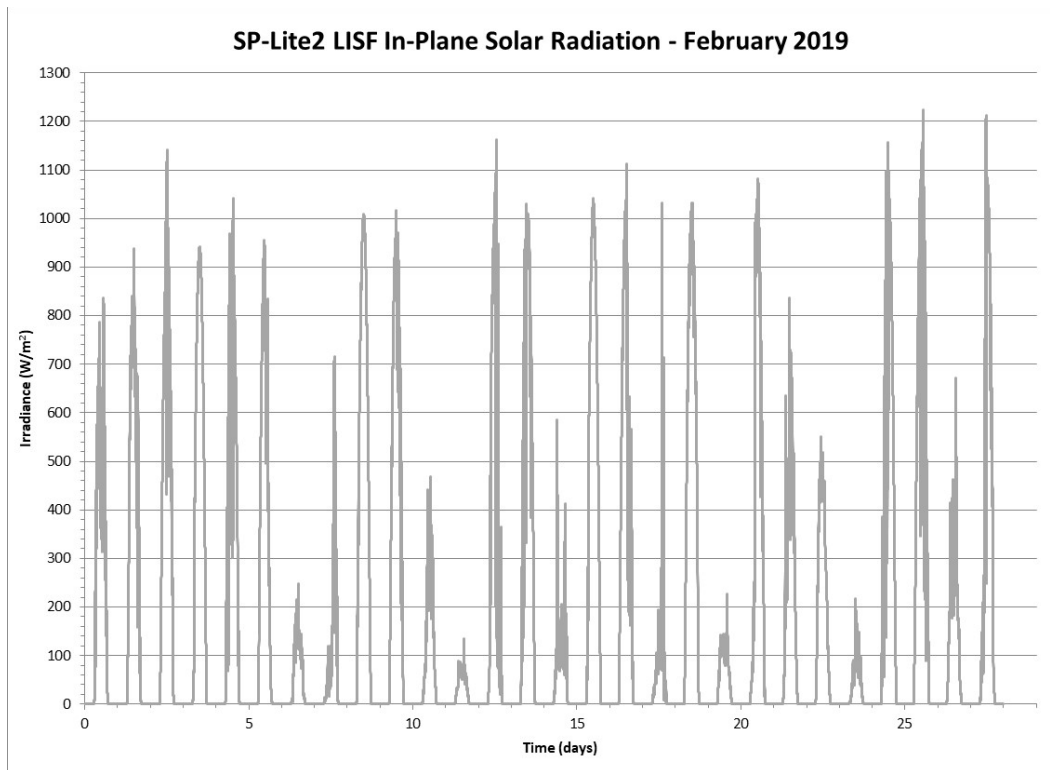


Figure 193 Tilted ( $27^\circ$ ) Global Solar Radiation from an SP-Lite2 Pyranometer for February 2019

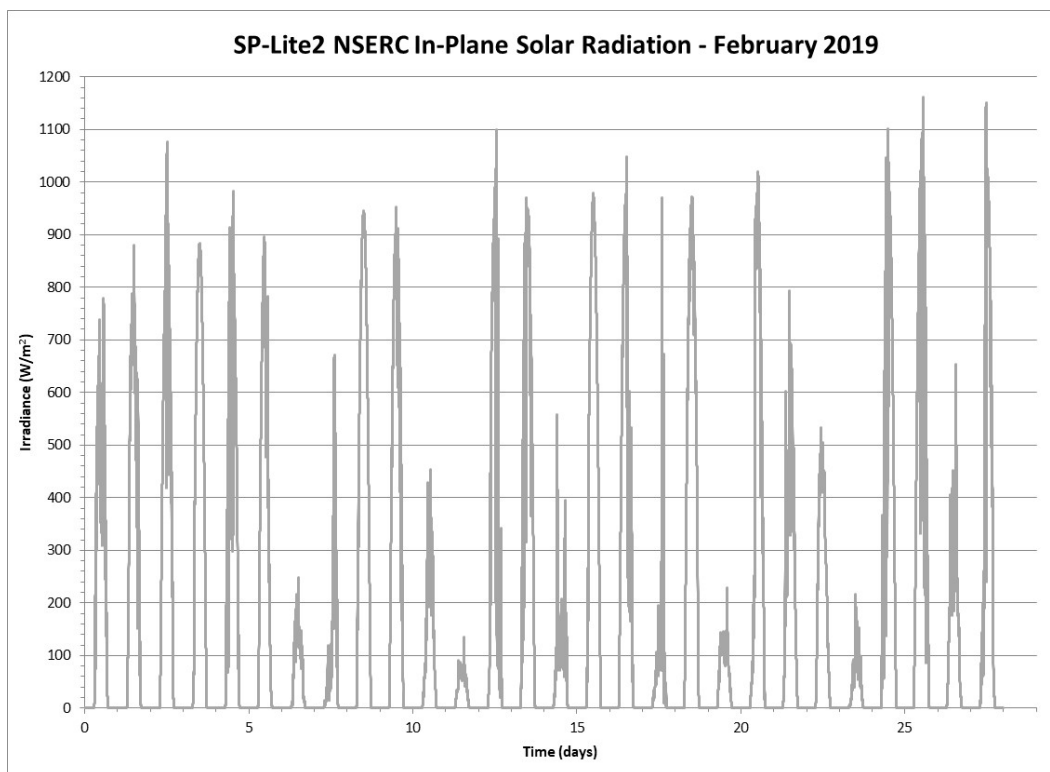


Figure 194 Tilted ( $23^\circ$ ) Global Solar Radiation from an SP-Lite2 Pyranometer for February 2019

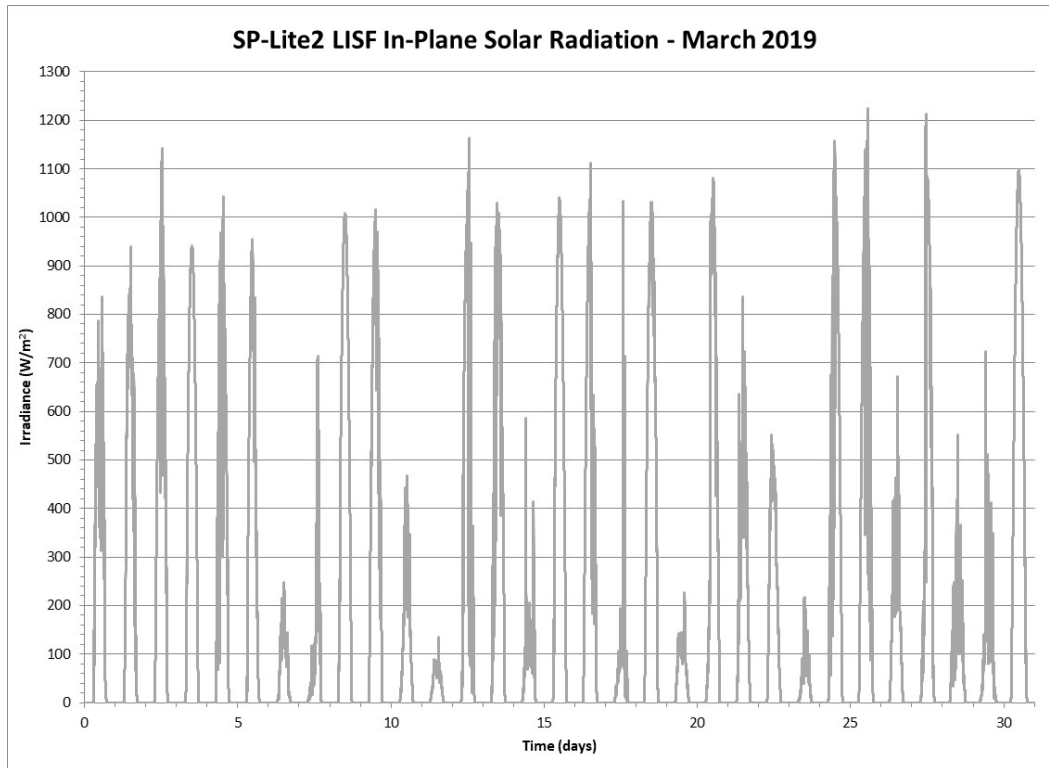


Figure 195 Tilted ( $27^\circ$ ) Global Solar Radiation from an SP-Lite2 Pyranometer for March 2019

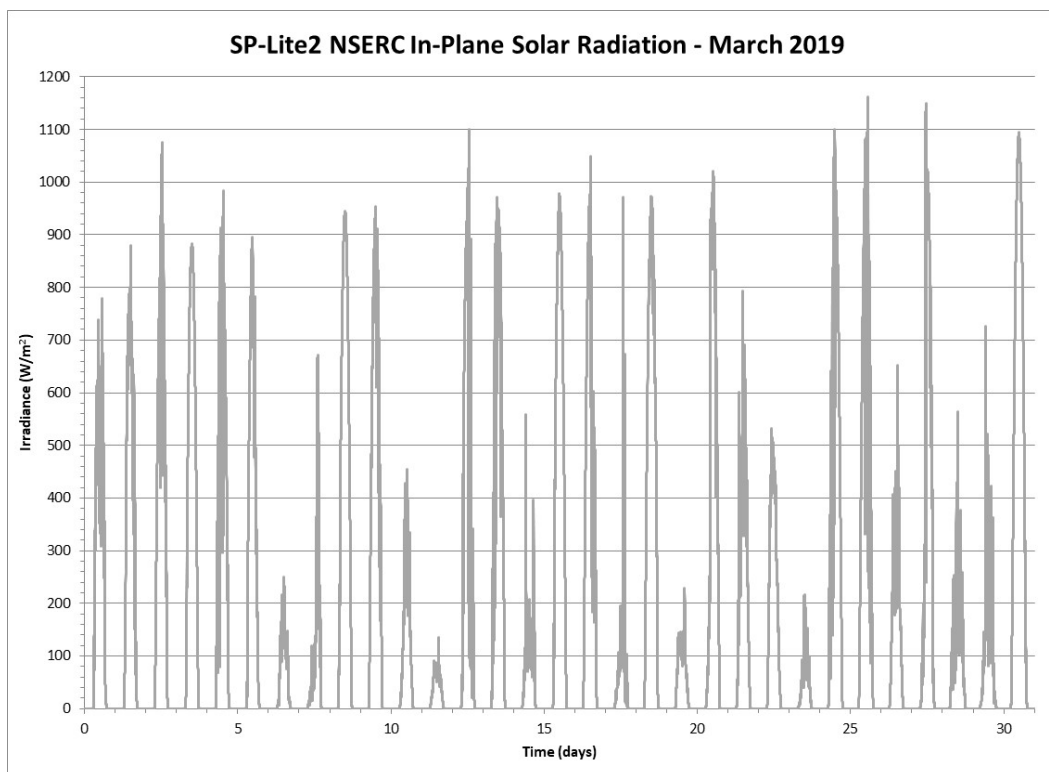


Figure 196 Tilted ( $23^\circ$ ) Global Solar Radiation from an SP-Lite2 Pyranometer for March 2019

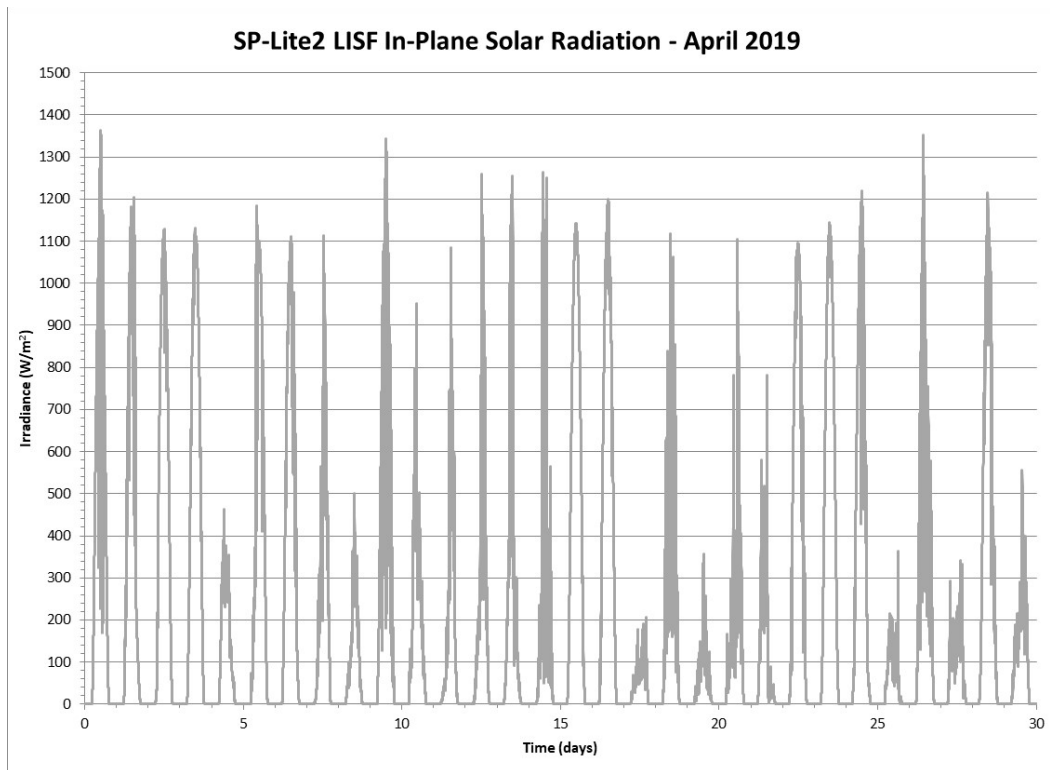


Figure 197 Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for April 2019

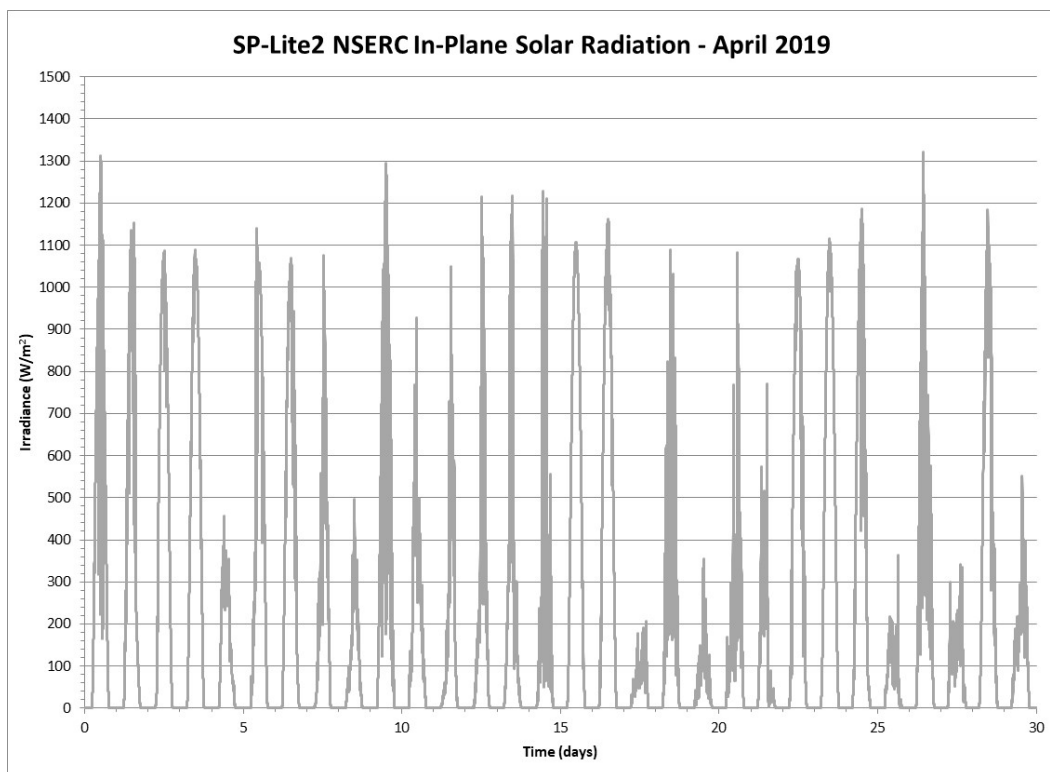


Figure 198 Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for April 2019

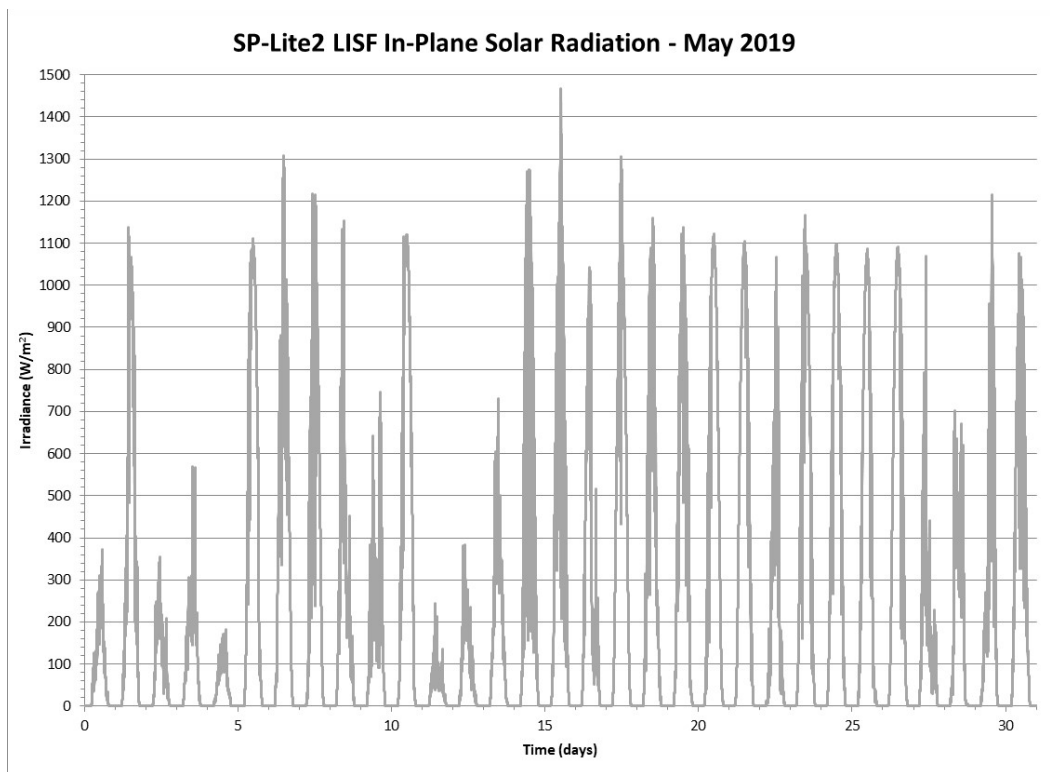


Figure 199 Tilted ( $27^\circ$ ) Global Solar Radiation from an SP-Lite2 Pyranometer for May 2019

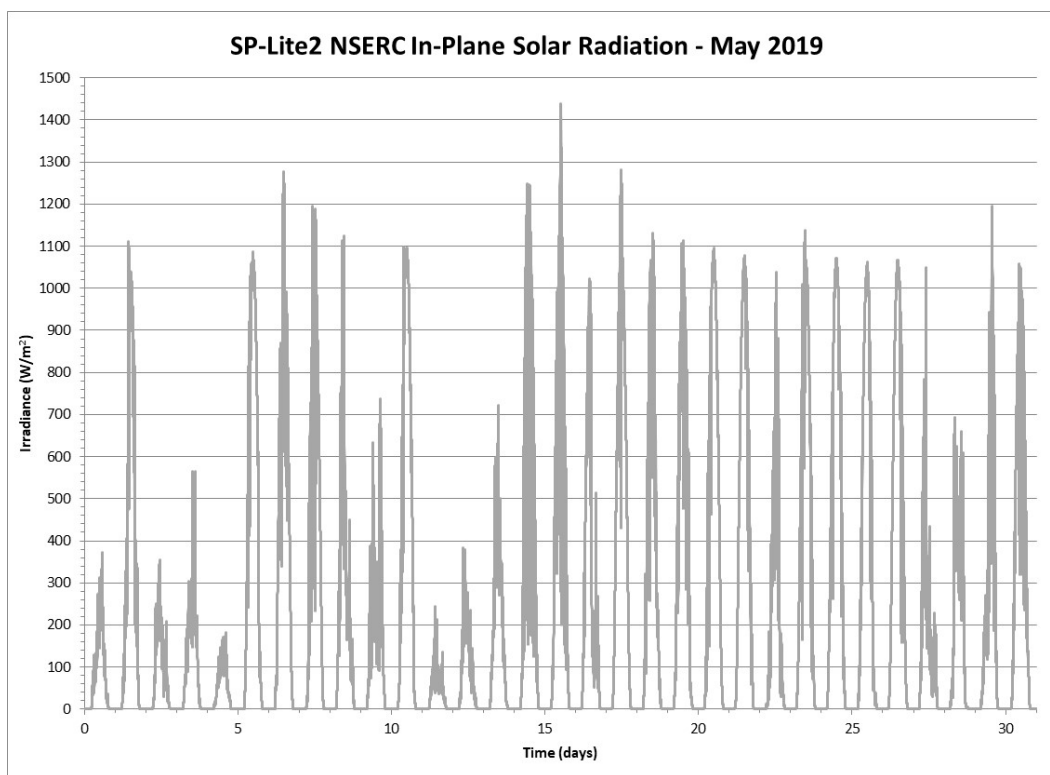


Figure 200 Tilted ( $23^\circ$ ) Global Solar Radiation from an SP-Lite2 Pyranometer for May 2019

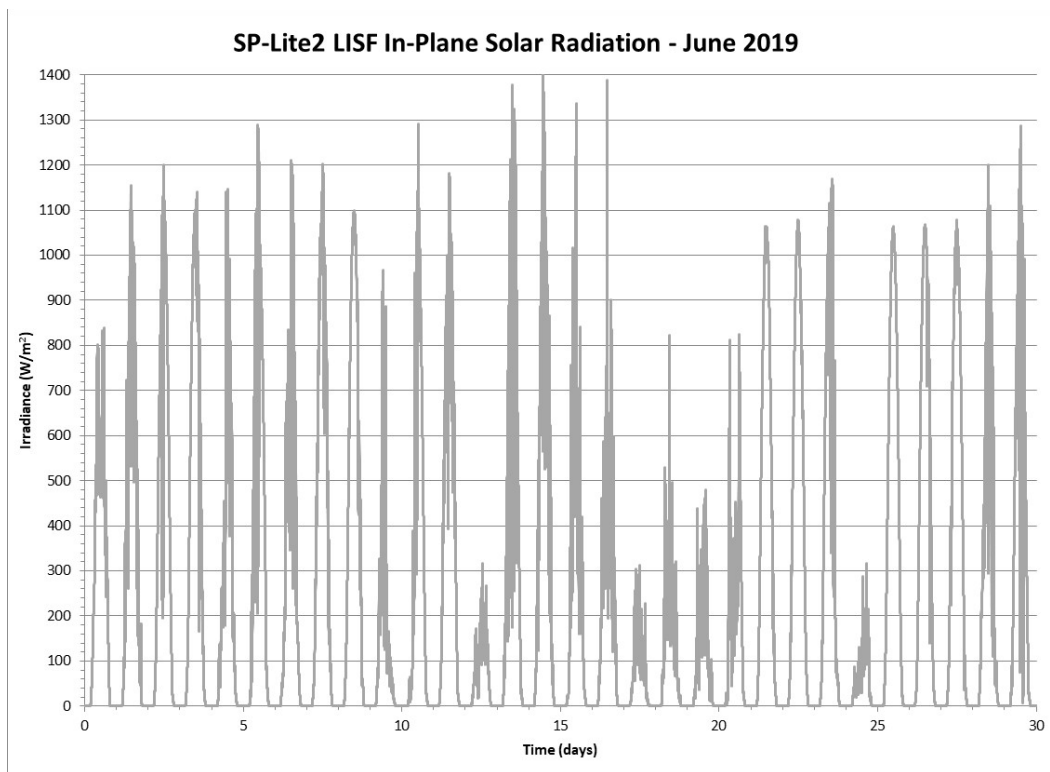


Figure 201 Tilted ( $27^\circ$ ) Global Solar Radiation from an SP-Lite2 Pyranometer for June 2019

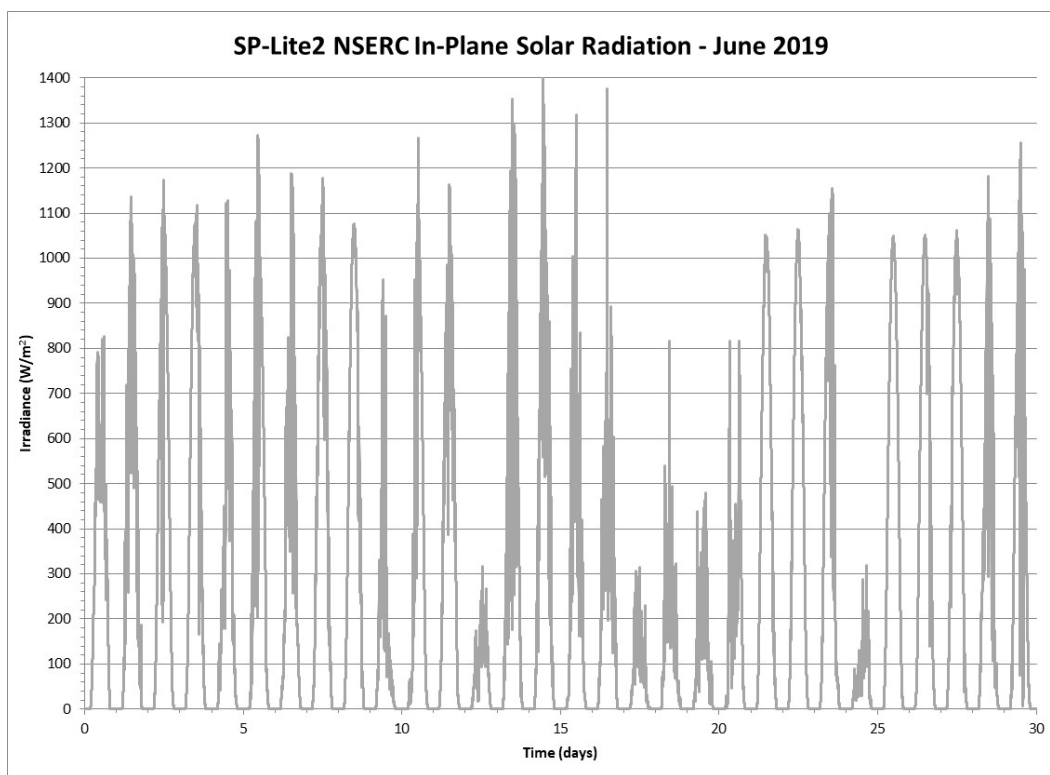


Figure 202 Tilted ( $23^\circ$ ) Global Solar Radiation from an SP-Lite2 Pyranometer for June 2019

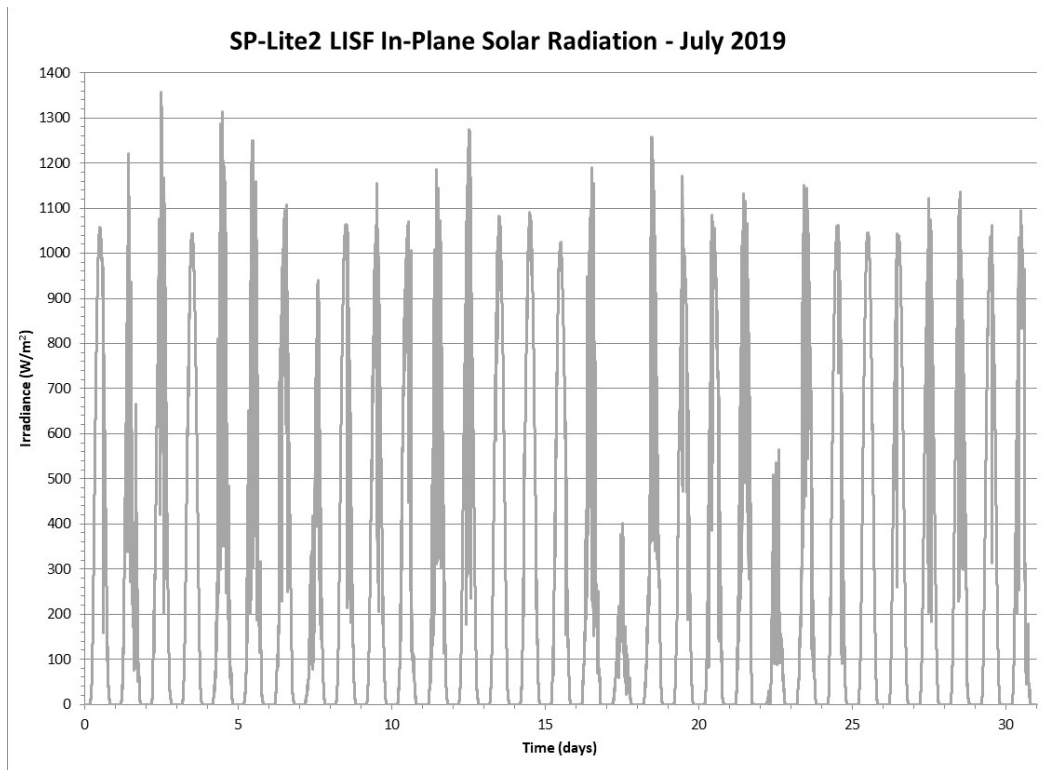


Figure 203 Tilted ( $27^\circ$ ) Global Solar Radiation from an SP-Lite2 Pyranometer for July 2019

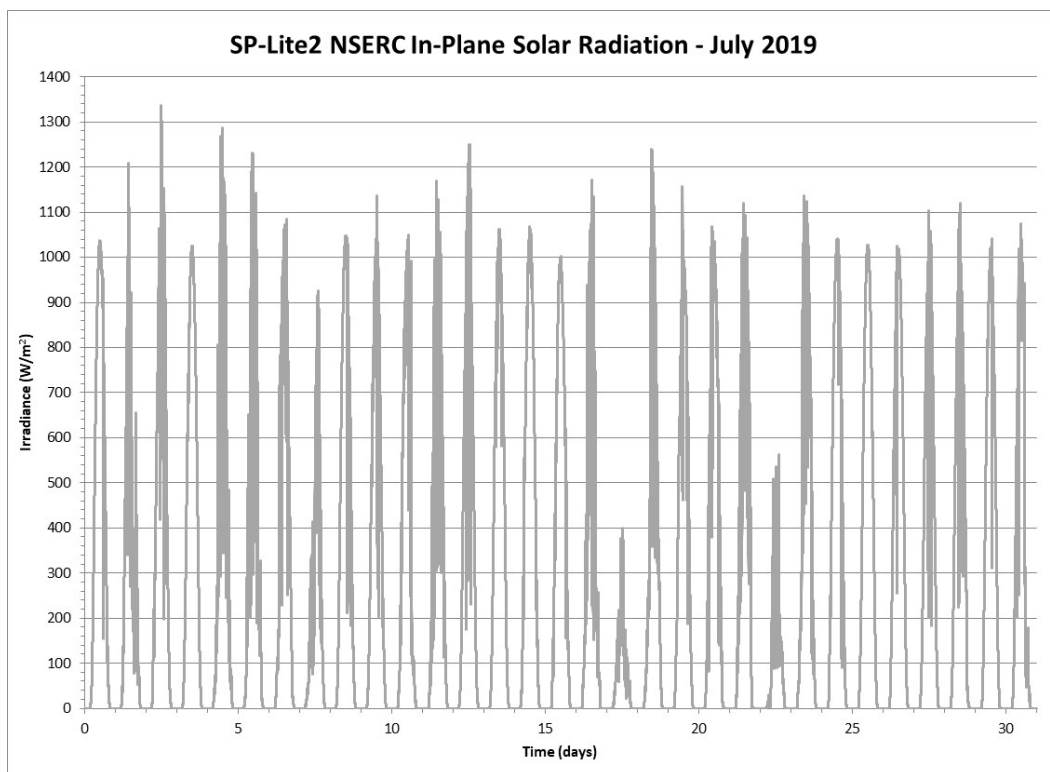


Figure 204 Tilted ( $23^\circ$ ) Global Solar Radiation from an SP-Lite2 Pyranometer for July 2019

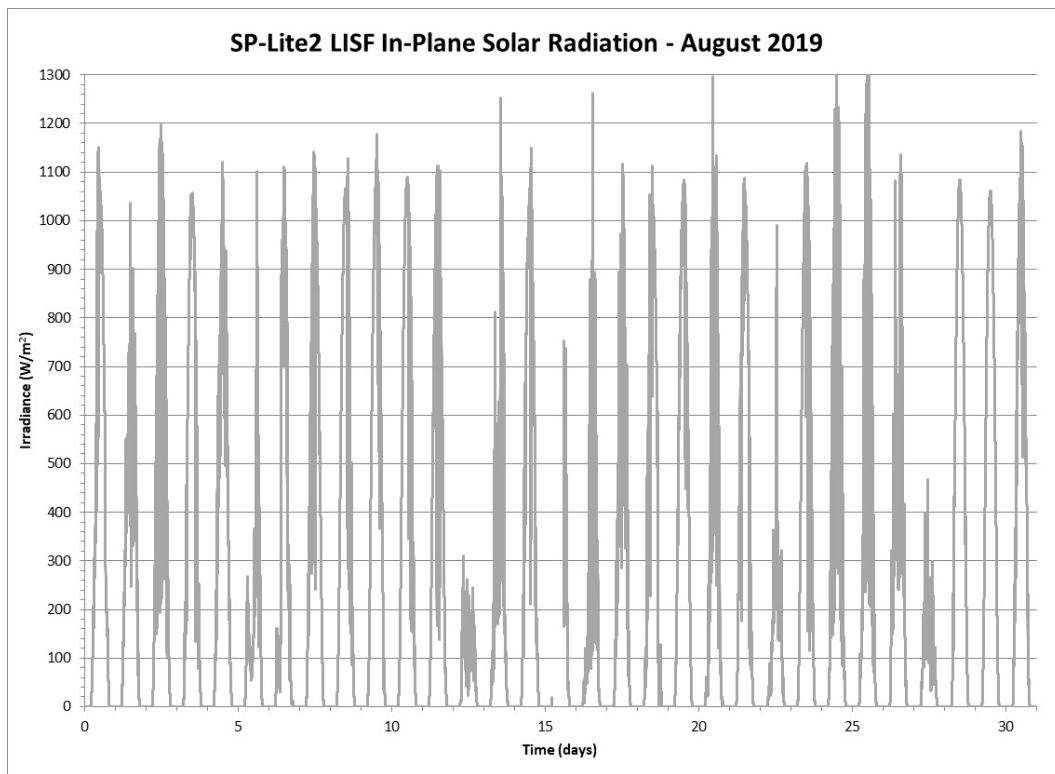


Figure 205 Tilted ( $27^\circ$ ) Global Solar Radiation from an SP-Lite2 Pyranometer for August 2019

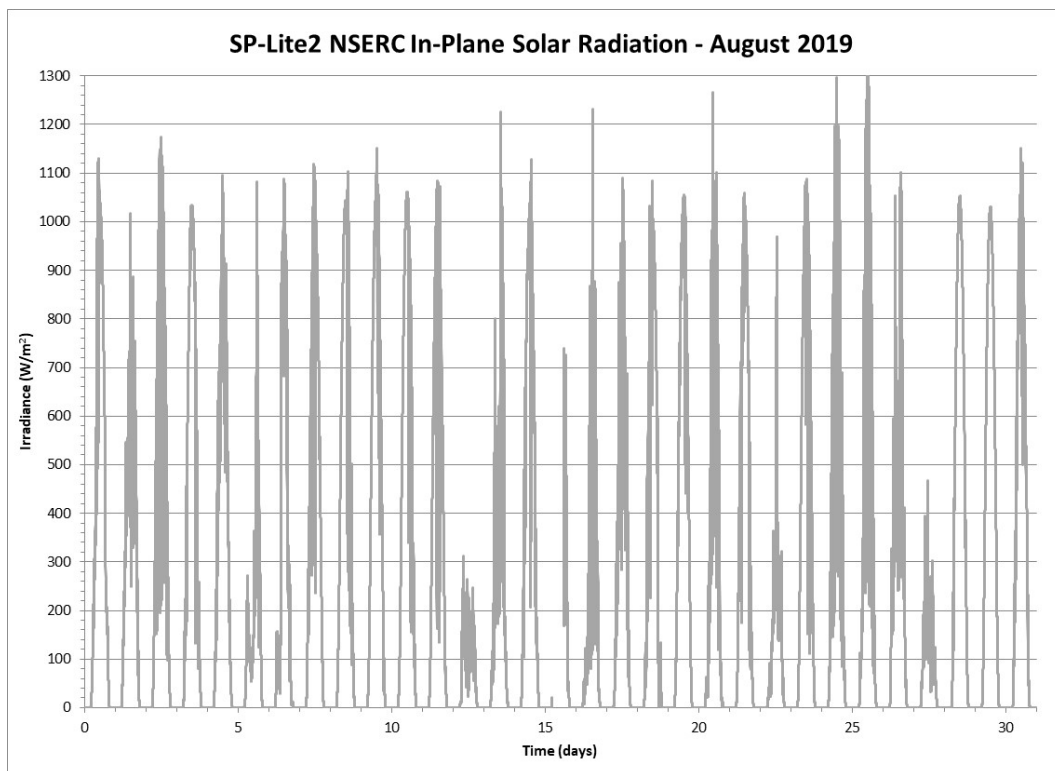


Figure 206 Tilted ( $23^\circ$ ) Global Solar Radiation from an SP-Lite2 Pyranometer for August 2019

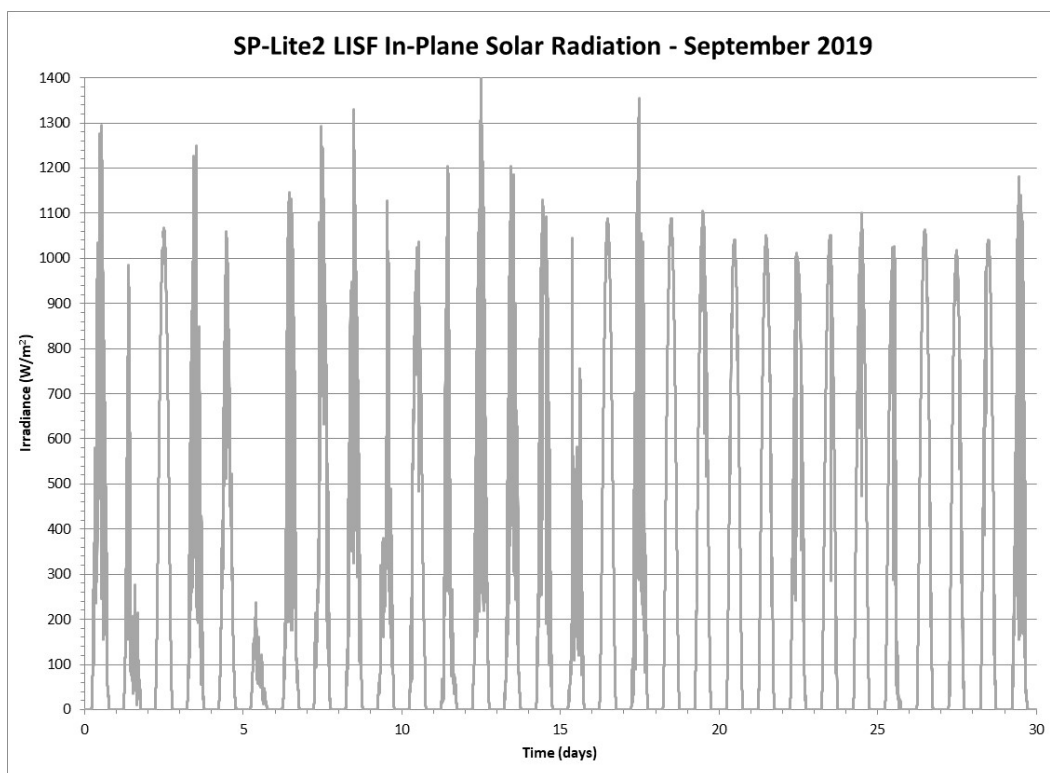


Figure 207 Tilted ( $27^\circ$ ) Global Solar Radiation from an SP-Lite2 Pyranometer for September 2019

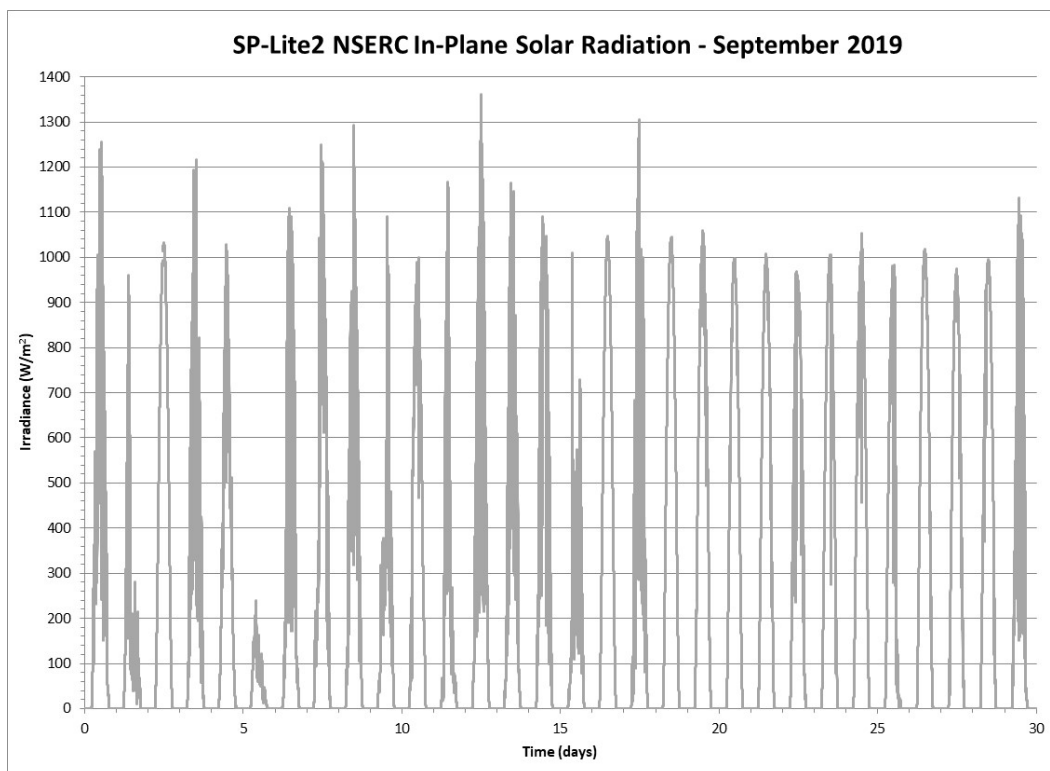


Figure 208 Tilted ( $23^\circ$ ) Global Solar Radiation from an SP-Lite2 Pyranometer for September 2019

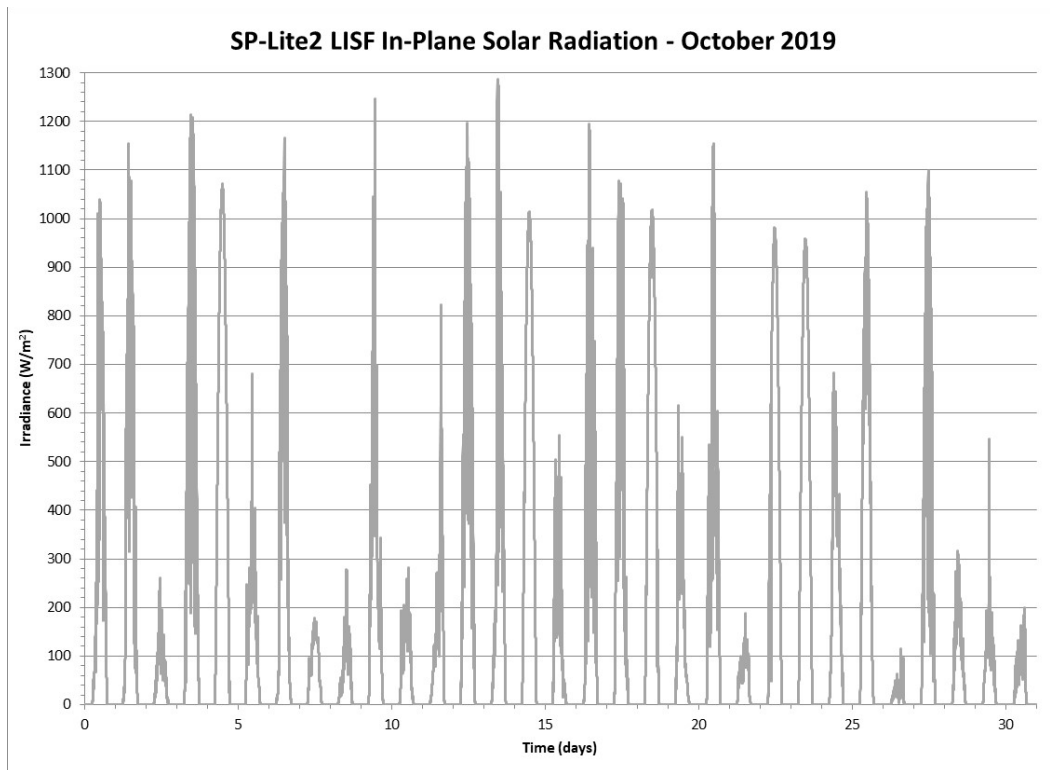


Figure 209 Tilted ( $27^\circ$ ) Global Solar Radiation from an SP-Lite2 Pyranometer for October 2019

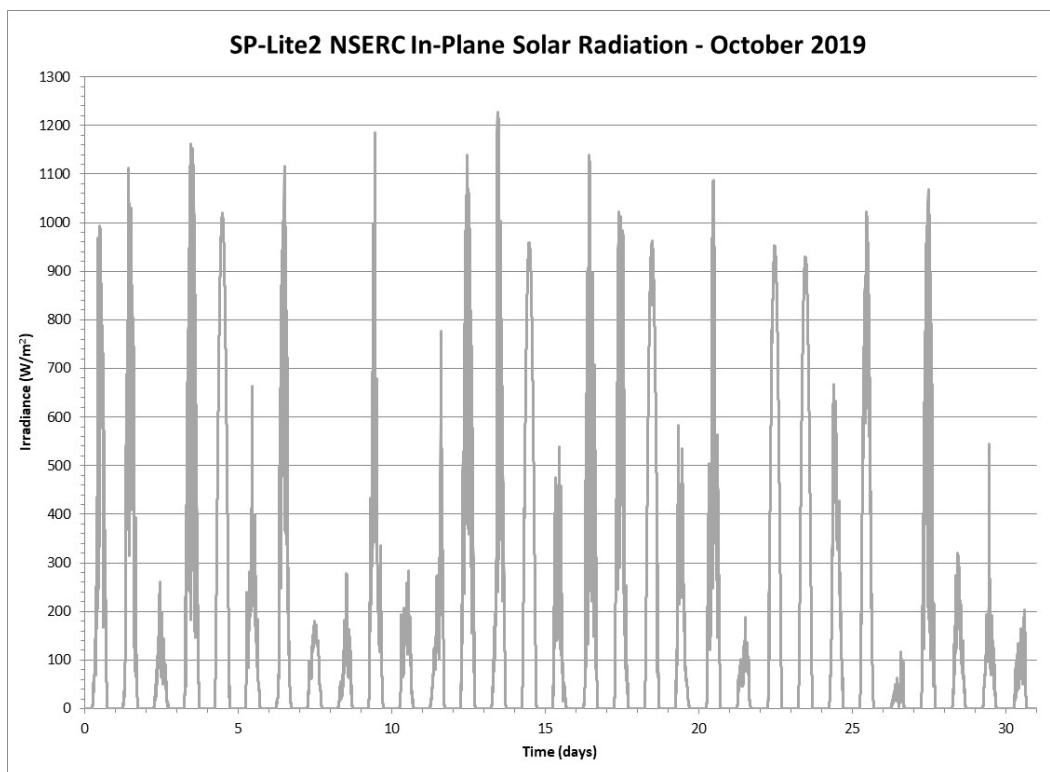


Figure 210 Tilted ( $23^\circ$ ) Global Solar Radiation from an SP-Lite2 Pyranometer for October 2019

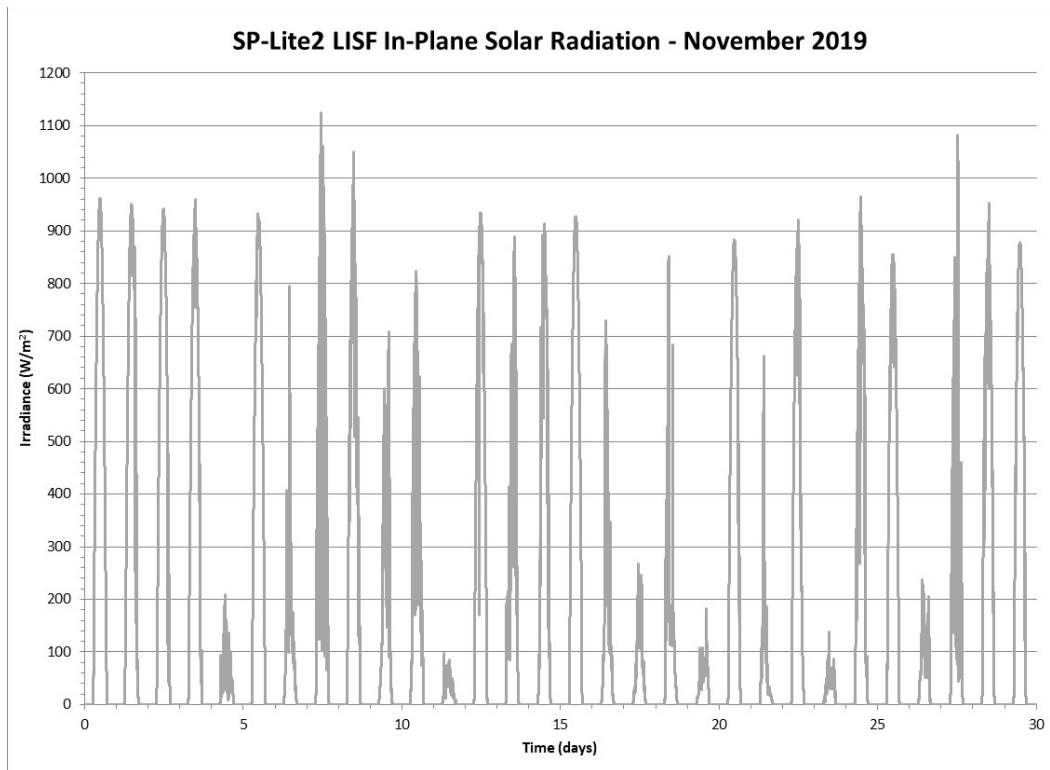


Figure 211 Tilted (27°) Global Solar Radiation from an SP-Lite2 Pyranometer for November 2019

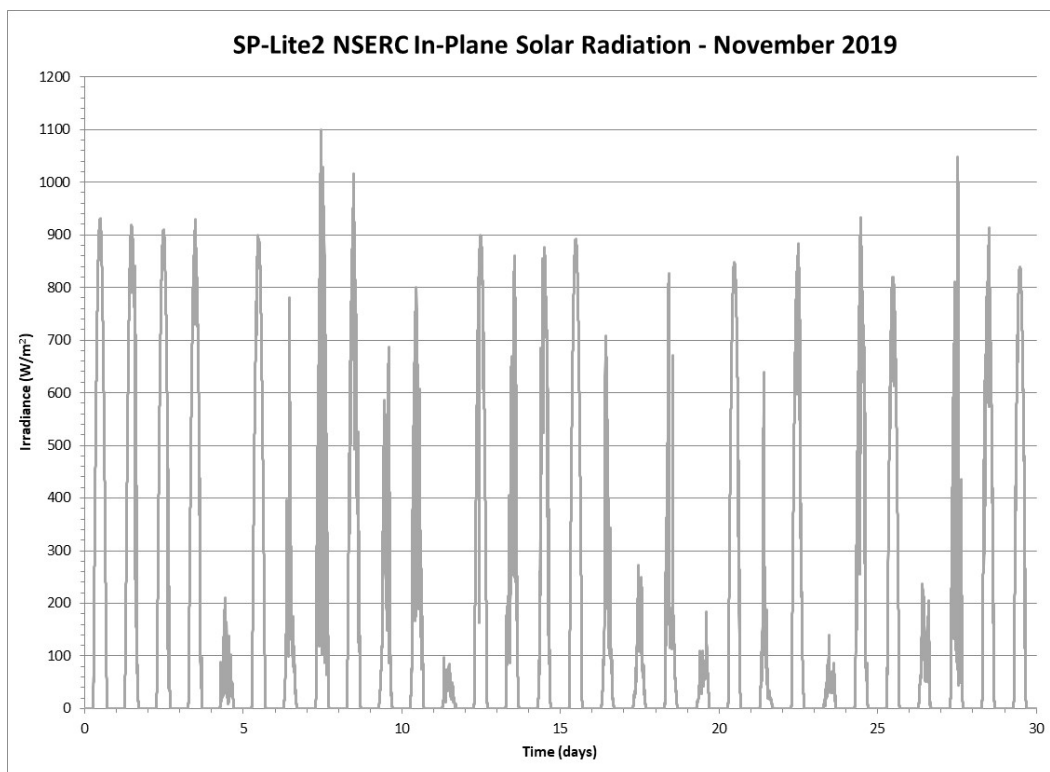


Figure 212 Tilted (23°) Global Solar Radiation from an SP-Lite2 Pyranometer for November 2019

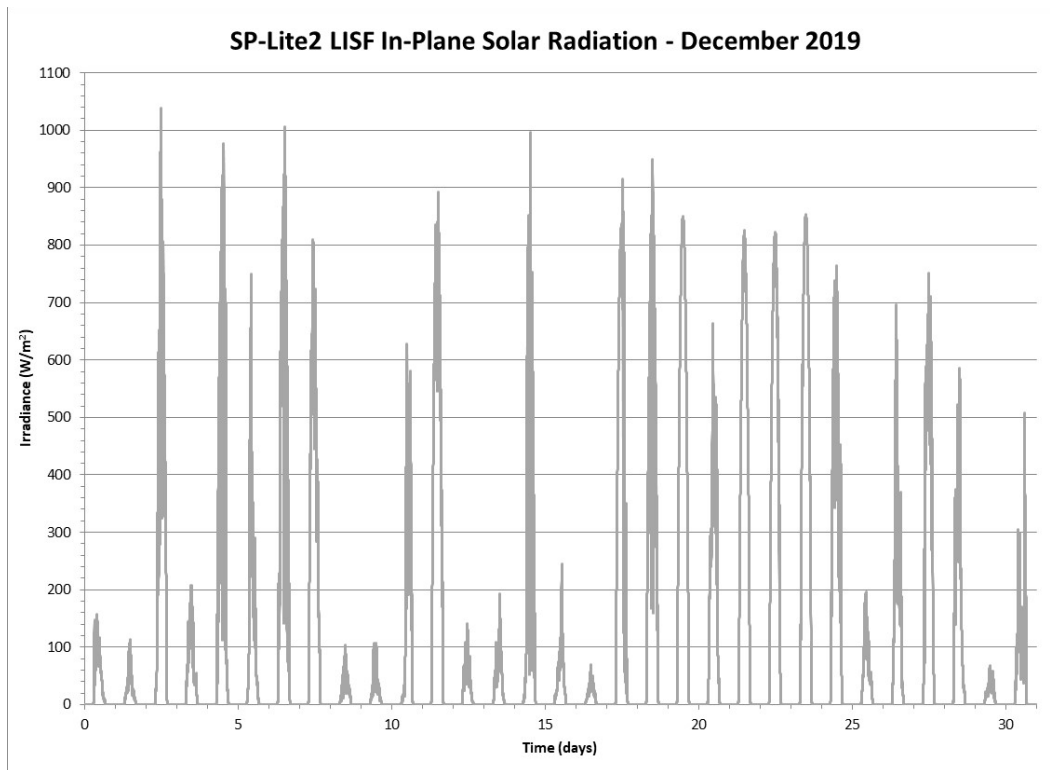


Figure 213 Tilted ( $27^\circ$ ) Global Solar Radiation from an SP-Lite2 Pyranometer for December 2019

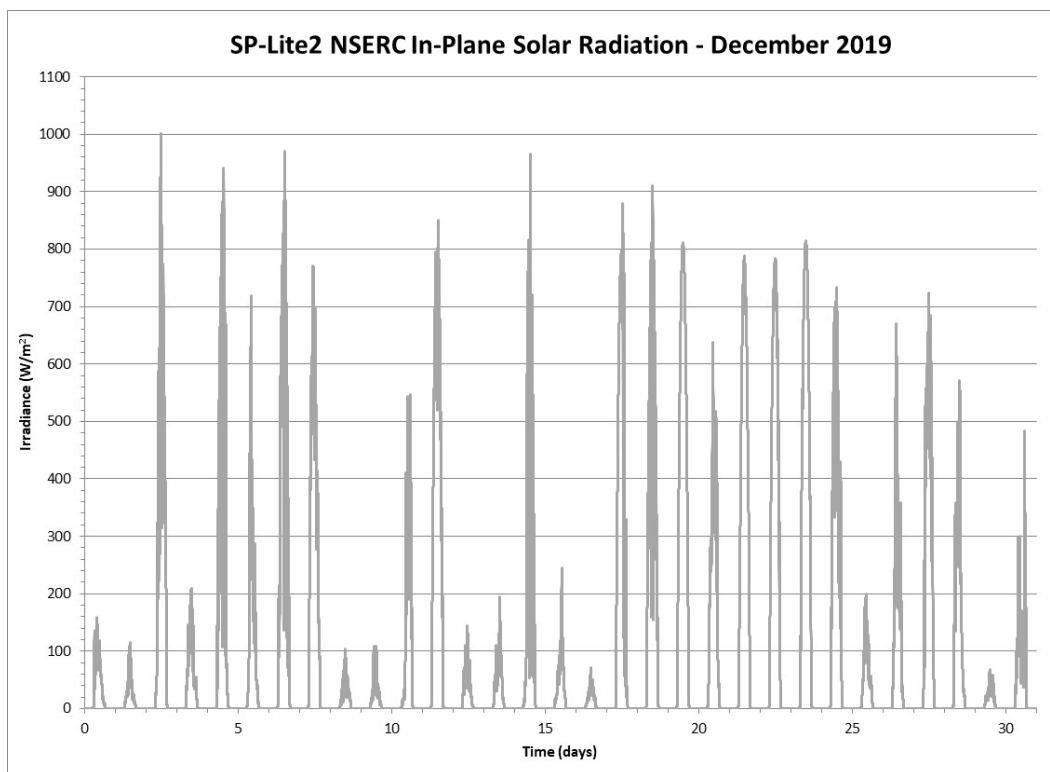


Figure 214 Tilted ( $23^\circ$ ) Global Solar Radiation from an SP-Lite2 Pyranometer for December 2019

## References

ASTM D6176-97 (reapproved 2008), Standard Practice for Measuring Surface Atmospheric Temperature with Electrical Resistance Temperature Sensors.

ASTM G183-05, Standard Practice for Field Use of Pyranometers, Pyrhemometers and UV Radiometers.

ASTM D3631-99 (reapproved 2007), Standard Test Methods for Measuring Surface Atmospheric Pressure.

American National Standard ANSI0ANS-3.11-2005, “Determining Meteorological Information at Nuclear Facilities”, American Nuclear Society, 2005.

Heiser, J., Instrument Calibration Plan and Procedures, Brookhaven National Laboratory Report BNL-99891-2013-IR, February 16, 2013.